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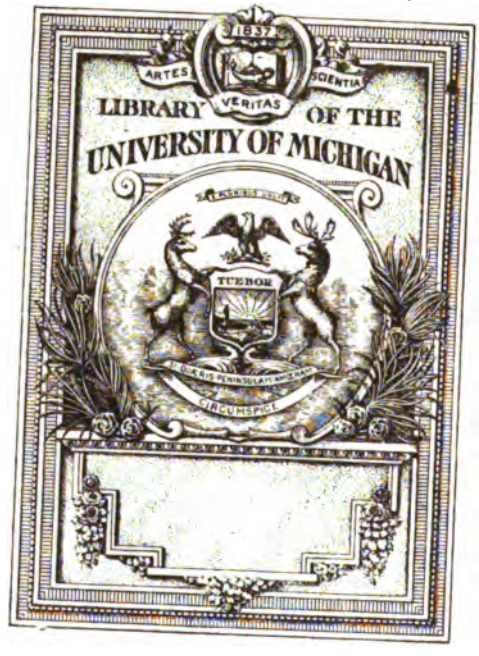
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DESCRIPTIVE MINERALOGY

DESCRIPTIVE MINERALOGY

BY

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WITH TWO HUNDRED AND SIXTY-EIGHT ILLUSTRATIONS

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TO
MY HELPER
MY WIFE
THIS BOOK IS
DEDICATED

315179

PREFACE

THE following pages are presented with the purpose of affording students a comprehensive view of modern mineralogy rather than a detailed knowledge of many minerals. The minerals selected for description are not necessarily those that are most common nor those that occur in greatest quantity. The list includes those that are of scientific interest or of economic importance, and, in addition, those that illustrate some principle employed in the classification of minerals. The volume is not a reference book. It is offered solely as a textbook. It does not pretend to furnish a complete discussion of the mineral kingdom, nor a means of determining the nature of any mineral that may be met with. The chapters devoted to the processes of determinative mineralogy are brief, and the familiar " key to the determination of species " is omitted. In place of the latter is a simple guide to the descriptions of minerals to be found in the body of the text. For more complete determinative tables the reader is referred to one of the many good books that are devoted entirely to this phase of the subject. In the descriptions of the characteristic crystals of minerals both the Naumann and the Miller systems of notation are employed, the former because of its almost general use in the more important reference books and the latter because of its almost universal use in modern crystallographic investigations. The student must be familiar with both notations. It is thought that this familiarity can be best acquired by employing the two notations side by side.

In preparing the descriptive matter the author has made extensive use of Hintze's *Handbuch der Mineralogie*. The figures illustrating crystal forms are taken from many sources. A few illustrations have

been made especially for this volume. Figures copied to illustrate special features are accredited to their authors. The statistics are mainly from the *Mineral Resources of the United States*. They are given for the year 1912 because this was a more nearly normal year in trade than any that has followed.

The author is under obligation to the McGraw-Hill Book Company for permission to reproduce a number of illustrations originally published in his *Elements of Crystallography*, and also for the use of the original engravings in making the plates for Figures 11, 33, 71, 90, 110, 114, 115, 118, 160, 191, 194, 224, 240, and 248.

W. S. BAYLEY.

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DESCRIPTIVE MINERALOGY

PART I

GENERAL CHEMICAL MINERALOGY

CHAPTER I

THE COMPOSITION AND CLASSIFICATION OF MINERALS

Definition of Mineral.—A mineral is a definite inorganic, chemical compound that occurs as a part of the earth's crust. It possesses characters which are functions of its composition and its structure. Most minerals are crystallized, but a few have been found only in an amorphous, colloidal condition. These are regarded as gels, or solid colloids.

The most essential feature of a mineral is its chemical composition, since upon this are believed to be dependent all its other properties.

Chemical Substances Occurring as Minerals.—The chemical substances found native as minerals may be classed as elements and compounds. The latter comprise chlorides, fluorides, sulphides, oxides, hydroxides, the salts of carbonic, sulphuric, phosphorus, arsenic, antimony and silicic acids, a large series of complicated compounds known as the sulpho-salts, a few derivatives of certain metallic acids—the aluminates and the ferrites—besides other salts of rarer occurrence, some simple and others exceedingly complicated, and possibly many solid solutions of gels or of a gel and a crystalloid. In some of these classes all the compounds are anhydrous. In others, some groups are anhydrous while the members of other groups contain one or more molecules of water of crystallization.

The sulphides, chlorides and fluorides are derivatives of H_2S, HCl, and H_2F_2, respectively. They may be regarded as having been produced from these compounds by the replacement of the hydrogen by metals. Illustrations: Cu_2S, CuS, NaCl, CaF_2.

The hydroxides and the oxides may be looked upon as derivatives of water, the hydroxides through the replacement of one atom of hydrogen by a metal, and the oxides through the replacement of both hydrogen atoms. The mineral, *brucite*, according to this view is $Mg\begin{matrix}OH\\OH\end{matrix}$, derived from $\begin{matrix}H(OH)\\H(OH)\end{matrix}$ by replacement of two hydrogen atoms in two molecules of water by one atom of Mg. *Cuprite* is $\begin{matrix}Cu\\Cu\end{matrix}O$, and *tenorite* CuO, the former derived by replacement of each atom of hydrogen in one molecule of water by an atom of Cu, and the latter by replacement of the two hydrogens by a single Cu.

The salts of carbonic acid (H_2CO_3) are the carbonates, those of sulphuric acid (H_2SO_4) the sulphates, those of orthophosphoric acid (H_3PO_4) the phosphates, those of orthoarsenic acid (H_3AsO_4) the arsenates, those of orthoantimonic acid (H_3SbO_4) the antimonates and those of the silicic acids, the silicates. There are, in addition, a few arsenites and antimonites that are salts of arsenious (H_3AsO_3) and antimonous (H_3SbO_3) acids.

The principal silicic acids whose salts occur as minerals are normal silicic acid (H_4SiO_4), metasilicic acid (H_2SiO_3), and trisilicic acid ($H_4Si_3O_8$). The metasilicic and the trisilicic acids may be regarded as normal silicic acid from which water has been abstracted, in the same way that pyrosulphuric acid is ordinary sulphuric acid less H_2O, thus: $2H_2SO_4 - H_2O = H_2S_2O_7$.

$$(HO)_4Si - H_2O = H_2SiO_3, \text{ metasilicic acid}$$
$$3(HO)_4Si - 4H_2O = H_4Si_3O_8, \text{ trisilicic acid.}$$

Fayalite is Fe_2SiO_4, *wollastonite*, $CaSiO_3$, and *orthoclase*, $KAlSi_3O_8$.

The aluminates and ferrites may be regarded as salts of the hypothetical acids AlO(OH) and FeO(OH), both of which exist as minerals, the first under the name *diaspore* and the second under the name *goethite*. *Spinel* is the magnesium aluminate, $Mg\begin{matrix}O-AlO\\O-AlO\end{matrix}$, ($MgAl_2O_4$), and *magnoferrite* the corresponding ferrate $MgFe_2O_4$. The very common mineral *magnetite* is the iron ferrate $Fe\begin{matrix}O-FeO\\O-FeO\end{matrix}$, or Fe_3O_4. In this compound the iron is partly in the ferrous and partly in the ferric state.

There are other minerals that differ from those of the classes above mentioned in containing more or less water of crystallization. These are usually separated from those in which there is no water of crystallization under the name of hydrous salts.

Besides the classes of minerals considered there are others which appear to be double salts, in which two substances that may exist independently occur combined to form a third substance with properties different from those of its components. *Cryolite*, $3NaF \cdot AlF_3$ or Na_3AlF_6, is an example. The sulpho-salts furnish many other examples.

Further, a large number of minerals are apparently isomorphous mixtures of several compounds. These are homogeneous mixtures of two or more substances that crystallize with the same symmetry, and, consequently, that may crystallize together. Their physical properties are continuous functions of their chemical compositions. Other minerals are apparently solid solutions in one another of simple crystallizable salts, of gels, of gels and salts, and of gels and adsorbed substances. Among these are some of the commoner silicates.

Determination of Mineral Composition.—Since the properties of minerals are functions of their chemical compositions, it is important that their compositions be known as accurately as possible. It is necessary in the first place that pure material may be secured for study. Pure material is most easily secured by making use of the differences in density exhibited by different compounds. The mineral to be studied is pounded to a powder, sifted through a bolting cloth sieve and shaken up with one of the heavy solutions employed in determining specific gravities. When the solution is brought to the same density as that of the mineral under investigation all material of a higher specific gravity will sink. The material with a density lower than that of the solution will rise to the surface. Material with a specific gravity identical with that of the solution will be suspended in it. If the mixing is done in a separating funnel of the proper type, the materials may be drawn off into beakers in the order of their densities, and thus the pure mineral may be separated from the impurities that were originally incorporated with it. After the purity of the substance is assured by examination under the microscope, it is ready for analysis.

The composition of the purified material is determined by the ordinary methods of chemistry known as analysis and synthesis.

In analysis the compound is broken into its constituent parts and these are weighed; or it is decomposed and its constituents are trans-

formed into known compounds which are weighed. From the weights thus obtained the proportions of the components in the original substance may be easily calculated if the weight of the original substance be known.

In synthesis the compound is built up from known elements or compounds.

If the mineral calcite ($CaCO_3$) is decomposed by heat into lime (CaO) and carbonic acid gas (CO_2), or if its components are transformed into the known compounds $CaSO_4$ and K_2CO_3, the process is analysis. If the known substance CO_2 is allowed to act upon the known substance CaO and the resulting product is a substance possessing all the properties of calcite, the process is synthesis.

Analytical Methods.—The analytical methods made use of in mineralogy are: (1) the ordinary wet methods of chemical analysis, (2) the dry methods of blowpipe analysis, in which the mineral is treated before the blowpipe without the use of liquid reagents except to a very subordinate degree, and (3) microchemical methods, performed on the stage of a compound microscope.

Blowpipe and microchemical analyses are made use of principally for the identification of minerals. By their aid the nature of the atoms in a compound may easily be learned, but the proportions in which these atoms are combined is determined only with the greatest difficulty. The methods are mainly qualitative.

Wet Analysis.—For exact determinations of composition the wet methods of chemistry are usually employed, since these are the most accurate ones. They are identical with the methods described in manuals of quantitative analysis, and therefore require no detailed discussion here. They are well illustrated by Prof. Tschermak as follows: If 734 mg. of the mineral *goethite* (in which qualitative tests show the presence of iron oxide and water) are roasted in a glass tube, water is given off. This when caught and condensed in a second tube containing dry calcium chloride increases the weight of this second tube by 75 mg. The residue of the mineral left in the first tube now weighs about 660 mg. An examination of this residue shows it to consist exclusively of the iron oxide (Fe_2O_3). Since only iron oxide and water are present in goethite the sum of these two constituents ought to equal the original weight of the mineral before roasting. But $660+75=735$, whereas the original weight was 734. The difference 1 mg. is due to unavoidable errors of manipulation. As it is very small it may be neglected in our calculations.

The results of the analysis are generally expressed in percentages,

which are obtained by dividing the weights of the different constituents by the weight of the original substance.

Thus: $660 \div 734 = 89.92$ per cent Fe_2O_3
$75 \div 734 = 10.22$ per cent H_2O

Total 100.14

The usual methods of analysis are, however, more indirect than this, the components of the substance to be analyzed being first transformed into known compounds and then weighed. For instance, common salt is known by qualitative tests to contain only Na and Cl. If 345 mg. of the pure salt be dissolved in water and the solution be treated with silver nitrate under proper conditions a precipitate of silver chloride is formed so long as any sodium chloride remains in the solution. The silver chloride is separated from the solution by filtration. It contains all the chloride present in the 345 mg. of salt. After drying, its weight is determined to be 840 mg. The solution from which the silver chloride was separated contains all the sodium that was originally present in the salt, but now it is in combination with nitric acid. It contains also any excess of silver nitrate that was added to precipitate the chlorine.

$$\underset{\text{salt}}{NaCl} + \underset{\text{reagent}}{AgNO_3} = \underset{\text{precipitate}}{AgCl} + \underset{\text{filtrate}}{NaNO_3}$$

The filtrate is now treated with hydrochloric acid to precipitate the excess silver. The silver chloride precipitate is removed by filtration, leaving a solution containing sodium salts of nitric and hydrochloric acids besides some free acid of each kind. Sulphuric acid is now added and the whole solution is evaporated to dryness. The free acids are driven off by the heat and the sodium salts are transformed into the sulphate, Na_2SO_4. The residue consisting exclusively of Na_2SO_4 is now found to weigh 419 mg.

The 345 mg. of salt have yielded 840 mg. of AgCl and 419 mg. of Na_2SO_4. The silver chloride is known to contain 24.74 per cent of chlorine and the sodium sulphate 32.39 per cent of sodium. The 840 mg. of AgCl contain 207.8 mg. of chlorine, and the 419 mg. of Na_2SO_4 contain 135.7 mg. of sodium. Hence 345 mg. of salt yield

207.8 mg. or 60.23 per cent Cl,
and 135.7 mg. or 39.34 per cent Na

343.5 mg. 99.57 per cent

Records of Analyses.—The composition of minerals like that of other chemical compounds is determined in percentages of their components and is recorded as parts per 100 by weight. A weighed quantity of the mineral is analyzed, the products of the analysis are weighed and the percentage of each constituent present is found by dividing its weight by the weight of the original substance, as has already been indicated.

In chemical treatises the results of the analyses are usually recorded in percentages of the elements present. In mineralogical works it is more common to write the percentage composition in terms of the oxides of the elements, partly because the old analyses are recorded in this way and partly because certain relations between the mineral components can be better exhibited by comparison of the oxides than by comparison of the elements present in them.

The record of the analysis of a *magnesite* may be given as:

Mg = 28.35 per cent, Fe = .34 per cent, C = 14.25 per cent, O = 56.98 per cent, Total = 99.92 per cent.	or as	MgO = 47.25 per cent, FeO = .43 per cent, CO_2 = 52.24 per cent, Total = 99.92 per cent.

Calculation of Formulas.—After the determination of the percentage composition of a mineral, the next step is to represent this composition by a chemical formula—a symbol which indicates the relative number of elementary atoms in the mineral's molecule, instead of the number of parts of its constituents in 100 parts of its substance.

The construction of a formula from the analytical results is simple enough in principle, but in practice it is often made difficult by the fact that many apparently pure substances are in reality composed of several distinct compounds so intimately intercrystallized that it is impossible to separate them. In the simplest cases the formula is derived directly from the results of the analyses by a mere process of division.

The atomic weights of the chemical elements are the relative weights of the smallest quantities that may enter into chemical combination with one another, measured in terms of the atomic weight of hydrogen which is taken as unity, or of oxygen taken as 16. Thus the atomic weights of nitrogen and oxygen are approximately 14 and 16 respectively, i.e., the smallest quantities of nitrogen and oxygen that can enter into combination with each other and with hydrogen are in the ratio of the

TABLE OF ATOMIC WEIGHTS

Element	Symbol	At. Weight
Aluminium	Al	27.1
Antimony	Sb	120.2
Argon	A	39.88
Arsenic	As	74.96
Barium	Ba	137.37
Bismuth	Bi	208.0
Boron	B	11.0
Bromine	Br	79.92
Cadmium	Cd	112.40
Caesium	Cs	132.81
Calcium	Ca	40.07
Carbon	C	12.005
Cerium	Ce	140.25
Chlorine	Cl	35.46
Chromium	Cr	52.0
Cobalt	Co	58.97
Columbium	Cb	93.5
Copper	Cu	63.57
Dysprosium	Dy	162.5
Erbium	Er	167.7
Europium	Eu	152.0
Fluorine	F	19.0
Gadolinium	Gd	157.3
Gallium	Ga	69.9
Germanium	Ge	72.5
Glucinum	Gl	9.1
Gold	Au	197.2
Helium	He	4.00
Holmium	Ho	163.5
Hydrogen	H	1.008
Indium	In	114.8
Iodine	I	126.92
Iridium	Ir	193.1
Iron	Fe	55.85
Krypton	Kr	82.92
Lanthanum	La	139.0
Lead	Pb	207.20
Lithium	Li	6.94
Lutecium	Lu	175.0
Magnesium	Mg	24.32
Manganese	Mn	54.93
Mercury	Hg	200.6
Molybdenum	Mo	96.0
Neodymium	Nd	144.3
Neon	Ne	20.2
Nickel	Ni	58.68
Niton	Nt	222.4
Nitrogen	N	14.01
Osmium	Os	190.9
Oxygen	O	16.0
Palladium	Pd	106.7
Phosphorus	P	31.04
Platinum	Pt	195.2
Potassium	K	39.10
Praseodymium	Pr	140.9
Radium	Ra	226.0
Rhodium	Rh	102.9
Rubidium	Rb	85.45
Ruthenium	Ru	101.7
Samarium	Sa	150.4
Scandium	Sc	44.1
Selenium	Se	79.2
Silicon	Si	28.3
Silver	Ag	107.88
Sodium	Na	23.0
Strontium	Sr	87.63
Sulphur	S	32.06
Tantalum	Ta	181.5
Tellurium	Te	127.5
Terbium	Tb	159.2
Thallium	Tl	204.0
Thorium	Th	232.4
Thulium	Tm	168.5
Tin	Sn	118.7
Titanium	Ti	48.1
Tungsten	W	184.0
Uranium	U	238.2
Vanadium	V	51.06
Xenon	Xe	130.2
Ytterbium (Neoytterbium)	Yb	173.5
Yttrium	Y	88.7
Zinc	Zn	65.37
Zirconium	Zr	90.6

values 14 : 16 : 1.[1] The quantities that possess these relative weights are known as atoms. Often the apparent ratios of the elements in combination are different from the ratios between their atomic weights, but this is always due to the fact that one or the other of the elements is present in more than its smallest possible quantity, i.e., in a greater amount than is represented by a single atom. For instance, there are several compounds of oxygen and nitrogen known, in which the weight relations between the two elements may be represented by the following figures: 14 : 8; 14 : 16; 14 : 24; 14 : 32, and 14 : 40. If the second of these compounds consists of one atom each of nitrogen and oxygen, and these are the smallest quantities of the elements that can exist in combination, the several compounds must be made up thus:

14 : 8	14 : 16	14 : 24	14 : 32	14 : 40
N_2O	NO	N_2O_3	NO_2	N_2O_5

for N can exist only in quantities that weigh 14, 28, 42 times as much as the smallest quantity of hydrogen present in any compound, i.e., the single atom, and O in quantities of 16, 32, 48, etc., times the weight of the single hydrogen atom. In order that even multiples of 14 and 16 shall exist in the ratios given above, their terms must be multiplied by quantities that will yield the following results:

28 : 16	14 : 16	28 : 48	14 : 32	28 : 80

which are the weights respectively of the numbers of atoms represented in the above formulas.

If, then, the elements combine in the ratio of their atomic weights, or in some multiple of this ratio, the figures obtained by analysis must be in one of these ratios, and consequently they furnish the data from which the formula of the substance analyzed may be deduced. In gold chloride, for example, analysis shows the presence of 64.87 per cent Au and 35.13 per cent Cl, i.e., the gold and the chlorine are united in the ratio of 64.87 : 35.13 or $\frac{64.87}{35.13}$. The combining ratio of single atoms of gold and of chlorine is, however, 196.7 : 35.5, or $\frac{196.7}{35.5}$. Evidently in gold chloride the ratio of gold to chlorine is only one-third as great as is the ratio between the atomic weights of these elements, or the ratio of the chlorine to the gold three times as great. Hence

[1] The atomic weight of hydrogen is more accurately 1.008, when that of oxygen is taken as 16.

there must be three times as much chlorine in gold chloride as would be represented by a single atom of chlorine, or there must be three atoms of chlorine in the compound, for we cannot imagine a quantity of gold present which is equivalent to one-third of an atom of gold. Gold chloride is therefore $AuCl_3$.

We can now prove our conclusion by calculation. One atom of gold and three atoms of chlorine ought to combine in the ratio of 196.7 : 106.5 (i.e., 35.5×3). If our conclusion is correct, and the gold chloride analyzed is $AuCl_3$, then the quantities of gold and of chlorine yielded by the analysis should be in this ratio. The figures obtained are in the ratio of 64.87 : 35.13. Multiplying both terms of this ratio by 3.031 we obtain 196.62 : 106.5, which is approximately the ratio expected.

In practice, the same result as that outlined above is reached by dividing the results of analyses by the atomic weights of the various elements or groups of elements concerned. The quotients represent the proportional numbers of the elements or groups present. If the smallest quotient is assumed as unity, the ratios existing between this and the other quotients indicate the number of atoms or groups of atoms represented by the latter.

Illustrations;

Gold Chloride		Result of Analysis		Atomic Weights		Quotients		Ratios
Au	=	64.87 per cent	÷	196.7	=	.3298	=	1
Cl	=	35.13	÷	35.5	=	.9896	=	3.00+
Tin Chloride								
Sn	=	45.26 per cent	÷	117.4	=	.384	=	1
Cl	=	54.74	÷	35.5	=	1.542	=	4.04

The formula of the gold chloride is $AuCl_3$, and of the tin chloride, $SnCl_4$.

Magnesium carbonate on analysis may yield: C = 14.26; Mg = 28.37; Fe = .34; O = 57.03; or, if recorded in the form of oxides: CO_2 = 52.24; MgO = 47.25; FeO = .43. From either of these results the formula is easily obtained by the method described.

$$\left.\begin{array}{r} C = 14.26 \div 11.97 = 1.188 = 1.009; \\ Mg = 28.37 \div 23.94 = 1.186 = 1.000; \\ Fe = \ .34 \div 55.88 = \ .006 = \ .006; \\ O = 57.03 \div 15.96 = 3.573 = 3.012; \end{array}\right\} \begin{array}{c} \text{or,} \\ MgCO_3\text{, if we neglect the small} \\ \text{quantity of iron present.} \end{array}$$

From the second set of figures we have:

$$\left.\begin{array}{l} CO_2 = 52.24 \div 43.89 = 1.19 = 1; \\ MgO = 47.25 \div 39.90 = 1.184 = 1; \\ FeO = \ \ .43 \div 71.84 = \ \ .006; \end{array}\right\} \begin{array}{l} \text{or,} \\ MgO \cdot CO_2, \text{ which is the same as} \\ MgCO_3, \text{ written in a different way.} \end{array}$$

All formulas are derived by methods like these, but in many cases the processes are made more difficult by the impossibility of deciding positively whether those substances that are present in small quantities are present as impurities or whether they exist as essential parts of the compound.

Formulas of Substances Containing Two or More Metallic Elements or Acid Groups.—In the illustration given above the compounds consist of but one kind of metallic element combined with one kind of acid. Often in the case of minerals there are present two or more metallic elements, and less commonly several acid groups. When two metals are present in definite atomic proportions the formula is written in the usual manner, as $CaMg(CO_3)_2$ for the mineral *dolomite*, in which calcium and magnesium are present in the ratio of one atom of each to two parts of the acid group CO_3. Very often, and perhaps in the majority of cases, when two or more metallic elements are present in different specimens of a mineral they are not found always in the same proportion—the mineral may consist of isomorphic mixtures of several substances. For instance, many calcium-magnesium carbonates are known in which the ratio of calcium to magnesium present is not as 1 atom to 1 atom, but in which this ratio is as 2 atoms to 1 atom, 3 atoms to 2 atoms, or a ratio which would have to be represented by irrational figures like 2.7236 atoms to 1.5973 atoms. Each one of these compounds properly requires a separate formula, as $2CaCO_3 + MgCO_3$, $3CaCO_3 + 2MgCO_3$, etc., but practically the entire series of compounds is represented by a single symbol, thus: $(Ca \cdot Mg)CO_3$, indicating that in the series we have to do with mixtures of carbonates of calcium and magnesium, or with complex molecules containing in different instances different proportions of the two carbonates. For greater definiteness the symbol of the characteristic element of the substance which is in largest quantity in the compound is usually written first, as $(Ca \cdot Mg)CO_3$, when calcium carbonate is in excess, or $(Mg \cdot Ca)CO_3$ when magnesium carbonate predominates. If still greater definiteness is desired small figures are placed below the symbols of the elements concerned, as $(Ca_2 \cdot Mg_1)CO_3$ or $(Ca_3 \cdot Mg_2)CO_3$, to indicate the respective proportions present. $(Ca_2 \cdot Mg_1)CO_3$ signifies that the

mineral thus represented contains calcium and magnesium in the ratio of 2 atoms of the former to 1 of the latter.

Compounds Containing Water.—Often salts that separate from aqueous solutions combine with certain definite proportions of water. Sometimes this water combines with the anhydrous portion of the compound to form a double salt, as $MgSO_4+7H_2O$, or $MgSO_4 \cdot 7H_2O$. At other times a portion of the water, in the form of the group (OH), called the hydroxyl group, occupies the place usually occupied by a metallic element, and, occasionally, that usually occupied by an acid group, or by oxygen, as in $Mg(OH)_2$.

Water of Crystallization.—Double salts composed of an anhydrous portion combined with water are usually well crystallized. Although the water appears in many cases to be but loosely combined with the remainder of the compound it is an essential part of its crystal particle, for by the loss of even a portion of it the crystal system of the compound is often changed. Water in this form is known as water of crystallization, and the compounds are designated *hydrates*.

The magnesium sulphate $MgSO_4 \cdot 7H_2O$ forms orthorhombic crystals. By evaporation of a hot solution of this substance the sulphate $MgSO_4 \cdot 6H_2O$ separates as monoclinic crystals.

Gypsum is $CaSO_4 \cdot 2H_2O$. Its crystallization is monoclinic. When heated to 200° it passes into the anhydrous orthorhombic mineral *anhydrite*, $CaSO_4$.

Water of crystallization may frequently be driven from the compound in which it exists by continued heating at a comparatively low temperature. It is usually given off gradually—an increase in the temperature causing an increase in the quantity of water released until finally the last trace disappears. In many instances such a very high temperature is required to drive off the last traces of the water that it would appear that some of it is held in combination in a different manner from that in which the remainder is held. Indeed, it is not at all certain that double salts containing water of crystallization are different in any essential respect from ordinary atomic molecules in which hydrogen and oxygen are present in atomic form.

Combined Water.—Water of crystallization is thought of as existing in the compound as water because of the ease with which it can be driven off. Compounds in which the hydroxyl group is present yield water only upon being heated to comparatively high temperatures. In them the elements of water are present, but not united as water. When freed from their combinations with the other constituents of the compound by heat they unite to form water. Because its elements

are thought of as closely combined with the other elements in the molecule, this kind of water is often distinguished from water of crystallization by the term combined water.

Brucite ($Mg(OH)_2$) and *malachite* ($Cu_2(OH)_2CO_3$) are minerals containing the elements of water. When heated they yield water according to the reactions $Mg(OH)_2 = MgO + H_2O$ and $Cu_2(OH)_2CO_3 = CuO + CuCO_3 + H_2O$.

Combined water is not only more difficult to separate from its combination than is water of crystallization, but when the combination is broken the chemical character of the original substance is radically changed, as may be seen from the reactions above indicated. Moreover, combined water is given off suddenly, at a certain minimum temperature, and not gradually as in the case of water of crystallization.

Blowpipe Analysis.—Although blowpipe analysis serves merely to identify the chemical components of minerals, it is a most important aid to mineralogists in their practical work.

Nearly all minerals may be recognized with a close degree of accuracy by their morphological and physical properties. To distinguish between several minerals that are nearly alike in these characteristics, however, the determination of composition is often important. In cases of this kind a single test made with the blowpipe will frequently give the desired information as to the nature of some one or more of the chemical elements present, and thus in a few moments the mineral may be identified beyond mistake.

The apparatus necessary to perform blowpipe analysis is very simple and the number of pieces few. These, together with all the reagents in sufficient quantity to determine the composition of hundreds of minerals, may be packed into a box no larger than a common lunch box. (See pp. 467–470.)

For more refined work than the mere testing of minerals a larger collection of both apparatus and reagents is necessary, but in no case is the quantity of material consumed in blowpipe analysis as great as when wet methods of analysis are used.

Principles Underlying Blowpipe Analysis.—The principal phenomena that are the basis of blowpipe work are the simple ones known in chemistry as volatilization, reduction, oxidation, and solution.

For volatilization experiments charcoal sticks and glass tubes are used. A blowpipe serves to direct a hot blast upon the assay. The volatilized products collect on the cool parts of the charcoal which they coat with a characteristic color, or upon the cooler portions of

the glass tubes. The sublimates that collect in the tubes may be tested with reagents or examined under the microscope.

Some volatile substances impart a distinct and characteristic color to an otherwise colorless flame. These may be tested in the direct flame of the blowpipe.

Oxidation and reduction experiments are usually performed either on charcoal or in glass tubes. Oxidations are effected in open tubes and reductions in those closed at one end. The products of the oxidation or of the reduction are studied and from their characteristics the nature of the original substance is inferred.

The solution of bodies to be tested is often made in the usual manner, i.e., by treating them with liquid reagents, but more frequently it is accomplished by fusion of a small quantity of the body with borax ($Na_2B_4O_7 \cdot 10H_2O$) or microcosmic salt ($(NH_4)NaHPO_4 \cdot 4H_2O$). The molten reagent dissolves a portion of the substance to be tested and in many cases forms with it a colored mass. From the color of the mass the nature of the coloring matter may be learned.

Although the underlying principles of blowpipe analysis are simple the reactions that take place between the reagents and the assay are often very complex.

More explicit details of the operations of qualitative blowpipe analysis are given in Part III.

Microchemical Analysis.—The processes of microchemical analysis are limited in their application to the detection of a single element or, at most, of a very few elements in small quantities of minerals. They are employed mainly in deciding upon the composition of a substance whose nature is suspected.

The principle at the basis of all microchemical methods is the manufacture of crystallized precipitates by treatment of the mineral under investigation with some reagent, and the identification of these precipitates through their optical and morphological properties.

In practice, a small particle of the mineral the nature of which it is desired to know is placed on a small glass plate, which may be covered with a thin film of Canada balsam to prevent corrosion, and is moistened with a drop or two of some reagent that will decompose it. The solution thus formed is slowly evaporated by exposure to the air. The plate is then placed beneath the objective of a microscope and the crystals formed during the evaporation are investigated. Or, after a solution of the assay is obtained there is added a small quantity of some reagent and the resulting precipitate is studied under the microscope. By their shapes and optical properties the nature of the

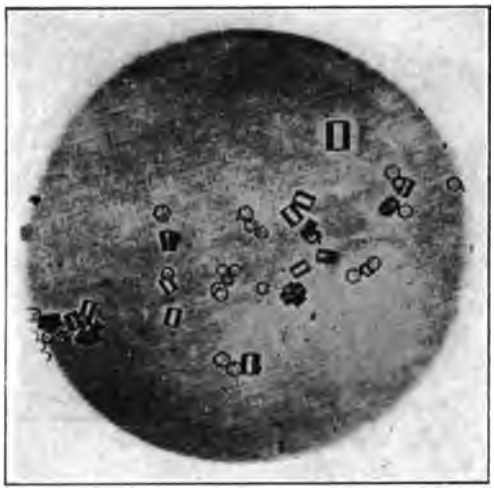


FIG. 1.—Sodium Fluosilicate Crystals. Magnified 72 diam. (*After Rosenbusch.*)

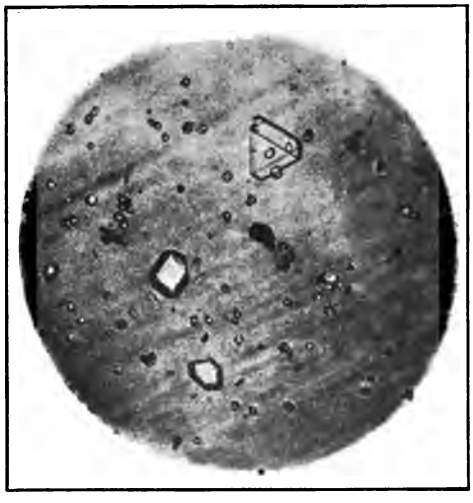


FIG. 2.—Potassium Fluosilicate Crystals. Magnified 140 diam. (*After Rosenbusch.*)

crystals produced is determined, and in this way the nature of the constituents they have obtained from the mineral particles is discovered.

A large number of reagents have been used in microchemical tests each of which is best suited to some particular condition. The most generally useful one is hydrofluosilicic acid (H_2SiF_6). If small fragments of *albite* and of *orthoclase* are placed on separate glass slips, such as are used for mounting microscopic objects, and each is treated with a drop of this reagent and then allowed to remain in contact with the air for a few minutes until the solutions begin to evaporate, those portions of the solutions remaining will be discovered to be filled with little crystals. The crystals in the solution surrounding the albite are hexagonal in habit (Fig. 1), while those in the solution surrounding the orthoclase are cubes, octahedrons or combinations of forms belonging to the isometric system (Fig. 2). The former are crystals of sodium fluosilicate and the latter crystals of the corresponding potassium salt. The albite, consequently, is a sodium compound and the orthoclase a compound of potassium. In similar manner, by means of this or of other reagents the constituents of many minerals may be easily detected. The method, however, is made use of only in special cases, when for some reason or other analytical methods are not applicable.

Synthesis.—Synthesis is the opposite of analysis. By the analytical processes compounds are torn apart, or broken down, whereas by synthetical operations they are put together or built up. Synthetic methods are employed principally in the study of the constitution of minerals and of their mode of formation, and in the investigation of the conditions that determine the different crystal habits of the same mineral. The products of synthetic reactions are often spoken of as artificial minerals because made through man's agency. In many instances these artificial minerals are identical in every sense with natural minerals. Consequently, they may often serve as material for study, when the quantity of the natural mineral obtainable is too small for the purpose.

Classification of Minerals.—Classification is the grouping of objects or phenomena in such a manner as will bring together those that are related or that are similar in many respects and will separate those that are different.

Since minerals are chemical compounds whose properties depend upon their compositions, their most logical classification must be based upon chemical relationships. But their morphological and physical properties are their most noticeable features, and hence these should also be taken into account in any classification that may be adopted. Probably the most satisfactory method of classifying minerals is to group them,

first, in accordance with their chemical relationships and, second, in accordance with their morphological and physical properties.

The first division is into the great chemical groups, as, for instance, the elements, the chlorides, the sulphides, etc. The second division is the separation of these great groups into smaller ones comprising minerals possessing the same general morphological features. These smaller groups may contain only a single mineral or they may contain a large number of closely allied ones. If the basis of the subgrouping is manner of crystallization, it follows that the members of subgroups containing more than one member are usually isomorphous compounds. Thus the subdivisions of the great chemical groups are single minerals and small or large isomorphous groups of minerals, arranged in the order in which their metallic elements are usually discussed in treatises on chemistry. For example, the great group of carbonates embraces all minerals that are salts of carbonic acid (H_2CO_3). This great group is divided into smaller groups along chemical lines, as for instance, the normal carbonates, the hydrous carbonates, the basic carbonates, etc. These smaller groups are finally divided into subgroups according to their morphological properties—the normal salts, for example, being divided into the two isomorphous groups known as the calcite and the aragonite groups, and a third group comprising but a single mineral.

In certain specific cases some other classification than the one outlined above may be desirable. For instance, in books written for mining students it is often found that a classification based upon the nature of the metallic constituent is of more interest than the more strictly scientific one outlined above, because such a classification emphasizes those components of the minerals with which the mining student is most concerned. In books written for the student of rocks, on the other hand, the most important determinative features of minerals are their morphological characters, hence in these the classification may be based primarily on manner of crystallization.

In the present volume the classification first outlined is used, but because such a small proportion of the known minerals are discussed the beauties of the classification are not as apparent as they would be were all described.

CHAPTER II

THE FORMATION OF MINERALS AND THEIR ALTERATIONS

The Origin of Minerals.—Minerals, like other terrestrial chemical compounds, are the result of reactions between chemical substances existing upon the earth. When they are the direct result of the action of elements or compounds not already existing as minerals they are said to be *primary* products; when formed by the action of chemical agents upon minerals already existing they are often spoken of as *secondary*, though this distinction of terms is not always applied.

Quartz (SiO_2), formed by the cooling of a molten magma, is primary; when formed by the action of water upon the siliceous constituents of rocks it is secondary.

The Formation of Primary Minerals.—Minerals are produced in a great variety of ways under a great variety of conditions. Even the same mineral may be produced by many different methods. The more common methods by which primary minerals are formed are: precipitation from a gas or a mixture of gases, precipitation from solution, the cooling of a molten magma, and abstraction from water or air by plants and animals.

Deposits from Gases.—Emanations of gases are common in volcanic districts. The gases escaping from volcanic vents are mainly water vapor, hydrochloric acid, sulphur dioxide, sulphuretted hydrogen, ammonia salts and carbon dioxide, besides small quantities of other gases and the vapors of various metallic compounds. By the reactions of these with one another or with the oxygen of the air, sulphur, salammoniac (NH_4Cl) and other substances may be formed, and by their reaction upon the rocks in the neighborhood halite ($NaCl$), ferric chloride ($FeCl_3$), hematite (Fe_2O_3) and many other compounds may be produced.

The production of minerals through the reactions set up between various gases and vapors is known as *pneumatolysis*. Their separation from the gaseous condition is known as *sublimation*. Minerals formed by sublimation are usually deposited as small, brilliant crystals on the surfaces of rocks or upon the walls of cavities and crevices in them.

The reactions by which they are produced are often quite simple. Thus the reaction between sulphuretted hydrogen and sulphur dioxide yields sulphur ($2H_2S+SO_2=3S+2H_2O$), as does also the reaction between the first named gas and the oxygen of the atmosphere ($H_2S+O=H_2O+S$). Ferric chloride may be produced by the action of hot hydrochloric acid upon some iron-bearing material deep within the earth's interior. This being volatile at high temperatures escapes to the air as a gas. Here it may react with water vapor, with the resulting formation of hematite ($2FeCl_3+3H_2O=Fe_2O_3+6HCl$). By the action of carbonic acid gas upon volatile oxides, carbonates are formed, ($Fe_2O_3+2CO_2=2FeCO_3+O$). In other cases, however, the reactions are very complicated.

Precipitation from Solution.—Nearly all substances are soluble to an appreciable degree in pure water. An increase in temperature usually increases the quantity of the substance that can be dissolved, as does also an increase of pressure. Moreover, the solubility of a salt is increased on the addition of another salt containing no common ion, and, conversely, is diminished in the presence of another having a common ion. Thus, gypsum ($CaSO_4 \cdot 2H_2O$) is sparingly soluble in water, but it becomes much more soluble upon the addition of salt ($NaCl$). On the other hand, salt ($NaCl$) is much less soluble in water containing a little magnesium chloride ($MgCl_2$) than it is in pure water.

When a solvent contains a maximum amount of any substance that it may hold under a given set of conditions the solution is said to be saturated. From a saturated solution under ordinary conditions precipitation results: Upon the evaporation of the solvent; the lowering of its temperature or of the pressure under which it exists; or the addition to the solution of a substance containing an ion already in the solution. Of course, the addition of a substance which will react with the solution and produce a compound insoluble in it will also cause precipitation.

The following table contains the results of various experiments on the solubility of some common minerals:

SOLUBILITY OF VARIOUS COMPOUNDS IN 100 PARTS PURE WATER

(The results are given in parts by weight)

Halite ($NaCl$), at 7°	35.68	Calcite ($CaCO_3$), in the cold	.002
Fluorite (CaF_2), at 15½°	.0037	Strontianite ($SrCO_3$) in the cold	.00555
Gypsum ($CaSO_4 \cdot 2H_2O$), at 15°	.250	Magnetite (F_3eO_4)	.00035
Anhydrite ($CaSO_4$), in the cold	.00025		
Celestite ($SrSO_4$), at 14°	.015		

PERCENTAGES OF VARIOUS MINERALS SOLUBLE IN WATER AT 80°
(When treated 30 to 32 days)

Galena (PbS)	1.79	Chalcopyrite ($CuFeS_2$)	.1669
Stibnite (Sb_2S_3)	5.01	Bournonite ($(Pb \cdot Cu)SbS_3$)	2.075
Pyrite (FeS_2)	2.99	Arsenopyrite (FeAsS)	1.5
Sphalerite (ZnS)	.025		

So many substances that are usually regarded as insoluble are known to be dissolved under conditions of high temperature and pressure that no substance is believed to be entirely insoluble.

Powdered apophyllite ($(HK)_2Ca(SiO_3)_2 \cdot H_2O$), which is a silicate that is generally regarded as insoluble in water, is dissolved sufficiently in this solvent at a temperature of 180°–190° and under a pressure of 10–12 atmospheres to yield crystals of the same substance upon cooling.

Water containing gases or traces of salts is usually a more efficient dissolving agent than pure water. When the gases are lost, or the salts are decomposed by reactions with other compounds, precipitation may ensue.

PARTS OF VARIOUS MINERALS DISSOLVED IN 10,000 PARTS OF VARIOUS SOLUTIONS

Gold loses 1.23 per cent of its weight when treated with 10 per cent soda solution at 200°.

One part *gypsum* ($CaSO_4 \cdot 2H_2O$) dissolves in 199 parts of saturated NaCl solution. Only .4 part dissolves in 200 parts pure water.

Pyrite (FeS_2) loses 10.6 per cent of its mass upon boiling for a long time with a solution of Na_2S. Under the same circumstances *galena* loses 2.3 per cent.

One of the commonest of the gases found in water on the earth's surface is carbon dioxide. This is an active agent in decomposing silicates and in dissolving carbonates, so that water in which it is dissolved is usually a more powerful solvent than pure water. Its dissolving power increases with the pressure, as in the case of pure water, but diminishes with increasing temperature. The action of carbonated water on silicates is due to the replacement of the silicic acid by carbonic acid and the production of bicarbonates, which are usually more soluble than the corresponding carbonates. The greater solubility of carbonates, like calcite, in carbonated water is also due to the formation of bicarbonates. For example, the action of carbonated water upon calcite ($CaCO_3$) is as follows:

$$CaCO_3 + H_2O + CO_2 = CaH_2(CO_3)_2.$$

Carbonated water is more effective as a solvent under pressure because of the inability of the CO_2 to escape under this condition. When pressure is removed the CO_2 escapes, or evaporation takes place, and the reverse reaction occurs, as:

$$CaH_2(CO_3)_2 = CaCO_3 + H_2O + CO_2.$$

The dissolving effect of carbonated water upon various carbonates and other minerals and the influence of pressure and temperature upon the solution of a carbonate are indicated in the three tables following:

SOLUBILITY OF CERTAIN CARBONATES IN 10,000 PARTS OF CARBONATED WATER

(The results are given in parts by weight)

Calcite ($CaCO_3$), at 10°	10.0	Siderite ($FeCO_3$) at 18°	7.2
Dolomite ($CaMg(CO_3)_2$) at 18°	3.1	Witherite ($BaCO_3$) at 10°	17.0
Magnesite ($MgCO_3$), at 5°	13.1	Strontianite ($SrCO_3$), at 10°	12.0

PERCENTAGES OF VARIOUS MINERALS SOLUBLE IN CARBONATED WATER

(When treated 7 weeks)

Adularia ($KAlSi_3O_8$)	.328	Apatite ($Ca_5(F \cdot Cl)(PO_4)_3$)	1.821
Oligoclase ($NaAlSi_3O_8 + CaAl(SiO)_4$)	.533	Apatite ($Ca_5(F \cdot Cl)(PO_4)_3$)	2.018
Hornblende (complex silicate)	1.536	Olivine ($(Mg \cdot Fe)_2SiO_4$)	2.111
Serpentine ($H_4Mg_3Si_2O_9$)	1.211	Magnetite (Fe_3O_4)	.307 to 1.821

INFLUENCE OF TEMPERATURE AND PRESSURE UPON THE SOLUTION OF MAGNESIUM CARBONATE ($MgCO_3$) IN CARBONATED WATER

(The results are given in parts per 10,000 by weight)

1 atmos. at 19°	2.579 parts	Temp. 13.4° under 1 atmos.	2.845 parts
3.2	3.730	29.3	2.195
5.6	4.620	62.0	1.035
7.5	5.120	82.0	.490
9.0	5.659	100.0	.000

Precipitation from Atmospheric Water.—Rain is an active agent in dissolving mineral matter. Since it absorbs small quantities of carbon dioxide, sulphur gases and other substances as it passes through the atmosphere it may act upon many compounds, dissolving some, decomposing others and forming soluble compounds from those that would otherwise be practically insoluble. Moreover, it transports the dissolved materials from one portion of the crust to some other portion, where, under favorable conditions, they may be precipitated. The rain water that penetrates the earth's crust, dissolving and precipitating in its

course through the crust, is known as *vadose* water. It is an important agent in ore-formation, since it may collect mineral matter from a great mass of rocks and precipitate it in some favorable place, thus making ore bodies.

Deposits of Springs.—Springs are the openings at which underground water escapes to the earth's surface. Much of the water flowing from springs is the meteoric water which has circulated through the crust and is again seeking the surface. In its course through the crust it dissolves certain materials. Where it reaches the surface some of this material may be dropped in consequence of (1) evaporation of the water, or (2) the escape of carbon dioxide, or (3) the oxidation of some of its constituents through the action of the air, or (4) the cooling of the water in the case of warm or hot springs.

The deposits thus formed may occur as thin coatings on the rocks over which the spring water passes, or as layers in the bottom of the spring and the stream issuing from it. Among the commonest minerals thus deposited are calcite ($CaCO_3$), aragonite ($CaCO_3$), siderite ($FeCO_3$) and other carbonates, gypsum ($CaSO_4 \cdot 2H_2O$), pyrite (FeS_2), sulphur (S), and limonite ($Fe_4O_3(OH)_6$). The carbonates are deposited largely in consequence of the escape of CO_2 from the water, gypsum in consequence of cooling, and limonite and sulphur through oxidation. If the water contains H_2S, this reacts with the oxygen and a deposit of sulphur ensues (compare p. 18).

When the precipitation occurs in cracks or fissures in the rocks the precipitated matter may partially or completely fill the fissure, producing a *vein;* or, the precipitated matter may fill an irregular cavern forming a *bonanza*. It sometimes covers the walls of cavities or the surfaces of minerals already existing, giving rise to a *druse*. In other cases precipitation may occur while the solution is dripping from an overhanging surface, making a *stalactite*, or the precipitate may fill the tiny crevices between grains of sand cementing the loose mass into a compact rock.

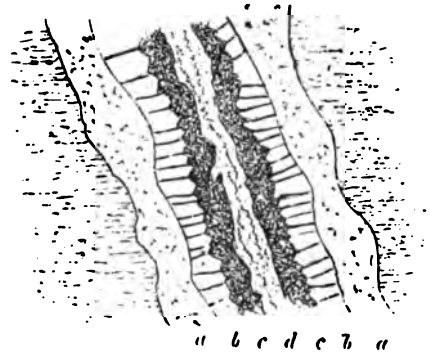


FIG. 3.—Cross-section of Symmetrical Vein. (*After Le Neve Foster.*)

(*a*) Decomposed rock. (*c*) Galena.
(*b*) Quartz crystals. (*d*) Siderite.

Minerals produced by precipitation are often beautifully crystallized.

At other times they form groups of needles yielding globular and other imitative shapes, while in still other instances they occur as pulverulent or amorphous masses. The fillings of veins are often arranged symmetrically, similar materials occurring on opposite sides of their central planes in bands, as shown in the figure (Fig. 3). Some important ores have been concentrated and deposited in this way.

Deposits from Hot Springs.—The water of hot springs deposits a greater variety of minerals than that of cold springs. Practically all minerals that are soluble in hot water or in hot solutions of salts are among them. Among those of economic value may be mentioned cinnabar (HgS) and stibnite (Sb_2S_3).

Deposits from the Ocean and Lakes.—The water of the ocean and of many lakes is rich in dissolved salts. That of lakes, however, is often saturated or nearly so, while that of the ocean is not near the saturation point. Consequently, while many lakes may deposit mineral substances, the ocean does not do so except under peculiar conditions. When a portion of the ocean is separated from the main body of water, it may evaporate and leave all of its mineral matter behind. Lakes may also completely evaporate with a similar result. In each case the deposits form layers or beds at the bottom of the basin in which the water was collected.

In other instances the water brought to the ocean or a lake may contain substances which will react with some of the materials already present and produce an insoluble compound which will be precipitated.

Of course, the nature of the beds thus formed will depend upon the character and proportions of the substances that were in the water. The ocean will yield practically the same kinds of compounds all over the world and the beds deposited by the evaporation of ocean water will be formed in nearly the same succession everywhere. In the case of enclosed bodies of water—like lakes or seas—in which the composition of the water may differ, the deposits formed may also differ.

Many of the deposits formed in bodies of water are of great economic importance and, consequently, are extensively worked. Probably the most important are the beds of salt (NaCl) and of gypsum ($CaSO_4 \cdot 2H_2O$), although borax ($Na_2B_4O_7 \cdot 10H_2O$) was formerly obtained in large quantity from the deposits of some of the lakes in the desert portions of the United States.

In the following table are given the results of analyses of water of the ocean and of Great Salt Lake, in Utah, calculated on the assumption that the elements are combined in the manner indicated in the

column on the left. The results of the analyses of the waters of a few noted lakes are given in the succeeding table.

COMPOSITION OF SALTS CONTAINED IN WATER OF THE OCEAN AND GREAT SALT LAKE

(Parts in 1000 of Water)

	I	II	III
$NaCl$	27.3726	8.1163	118.628
KCl	.5921	.1339	
$MgCl_2$	3.3625	.6115	14.908
$CaSO_4$	1.3229	.9004	.858
$MgSO_4$	2.2437	3.0855	
Na_2SO_4	.....	.....	9.321
K_2SO_4	.....	.....	5.363
$RbCl_2$	.0190	.0034	
$MgBr_2$	.0547	.0081	tr
$Ca_3(PO_4)_2$	.0156	.0021	
$CaCO_3$	.0434	.0780	
$FeCO_3$	.0019	.0011	
SiO_2	.0149	.0024	
	35.0433	12.9427	149.078

I. Water of N. Atlantic off Norwegian Coast. Analyst, C. Schmidt.
II. Average of Five Analyses, Caspian Sea at depths of from 1 m. to 640 m. Analyst, C. Schmidt.
III. Great Salt Lake, Utah. Analyst, O. D. Allen.

PERCENTAGE COMPOSITION OF THE RESIDUES OF A FEW LAKE WATERS

	Cl	Br	SO_4	CO_3	Na	K	Ca	Mg	SiO_2, etc.	Total Solids (per 1000 of Water).
Dead Sea	64.49	1.45	.45	.....	15.75	3.24	4.09	10.53	tr	220.3
Lake Beisk, Siberia	22.79	tr	42.32	.61	31.32	1.01	.07	1.86	.02	104.7
Goodenough Lake, B. C.	7.64	....	7.08	41.41	36.17	6.65	.02	.04	.99	103.47
Borax Lake, Cal.	32.27	.04	.13	22.47	38.10	1.52	.03	.35	.02	76.56

Deposits from Magmatic Water.—Equally important in depositing mineral matter is the water that escapes from cooling lavas and other molten magmas—designated as *juvenile* water. All molten magmas existing under pressure, i.e., at some distance beneath the crust, contain the components of water, which escape as the magma cools or when the pressure diminishes, whether the diminution of the pressure is due to

the escape of the lava to the surface or to the cracking of the crust. In its passage to the surface the hot water carrying dissolved salts penetrates all the cracks and cavities in the rocks through which it passes in its ascent and deposits its burden of material, forming veins and other types of deposits. Or, its components may decompose the materials with which it comes in contact, replacing them wholly or in part by the substances which it is carrying or by the products of decomposition.

FIG. 4.—Cross-section of Vein in Green Porphyry. The vein filling is chalcedony. The white splotches are feldspar crystals. The fairly uniform character of the rock where not affected by the vein is seen on the right side of the picture. The rude banding parallel to the vein is due to changes that have proceeded outward from the vein-mass into the rock.

Since in many cases magmatic water contains corrosive gases, such as fluorine, its action on the rocks which it traverses is profound. A tiny crack in the rocks may be gradually widened and the material on both sides of it be replaced by new material, thus producing a vein which is sometimes difficult to distinguish from a vein made in other ways (Fig. 4). This process is known as *metasomatism*, which is one kind of *metamorphism*. It is an important means of producing pseudomorphs and bodies of mineral matter sufficiently rich in metallic contents to constitute ore-bodies.

Solidification from Molten Magmas.—A molten magma, such as a liquid lava, is probably a solution of various substances—mainly silicates—in one another, or in a hot solvent. Upon cooling or upon change of conditions, such as may arise from loss of gas or water or from reduction of pressure, this hot solution gradually deposits some of its constituents as definite chemical compounds. Upon further cooling other compounds solidify and so on, until finally, if the rate of cooling has been slow, the entire mass may separate as an aggregate of minerals—such as constitute many of the rocks, as granite for instance, and many of the lavas. If the cooling has been rapid, some of the material may separate as definite minerals while the remainder solidifies as a homogeneous glass, as in the case of most lavas. Sometimes the minerals thus formed are bounded by crystal planes, but usually their growth has been so interfered with that it is only by their optical properties that they can be recognized as crystalline substances. The nature of the minerals that separate depends upon a great variety of conditions, the most important of which is the chemical composition of the magma.

In some cases the minerals separating from a magma tend to segregate in some limited portion of its mass and thus produce an accumulation that may be of economic value, i.e., the magma *differentiates*. Magnetite (Fe_3O_4), ilmenite ($(Fe \cdot Ti)_2O_3$), pyrite (FeS_2) and a few other minerals are sometimes segregated in this way in very large masses.

Metamorphic Minerals.—Many minerals are characteristic of rocks that are in contact with others that were once molten. They were formed by the gases and hot waters given off from the magmas before they cooled. The hot solutions with their charges of gas and salts penetrated the pores of the surrounding rock and deposited in them some of their material. They reacted with some of the rock's components, producing new compounds, and extracted others, leaving pores into which new supplies of gas and water might enter. In some cases the entire body of the surrounding rock has been replaced by new material for some distance from the contact. Beyond this belt of most profound *metamorphism* are other belts in which the rock is less altered, until finally in the outer belt is the unchanged original rock. Into the outer contact belt perhaps only gas penetrated and the changes here may be entirely *pneumatolytic*. Near the contact the changes may be *metasomatic*. Minerals formed by these processes near the contact of igneous masses are frequently referred to collectively as *contact minerals*.

In other cases new minerals may be produced in rocks in consequence of crushing attended by heat. Hot water under high pressure greatly facilitates chemical changes. A part of the materials of the

crushed rock dissolves, reactions are set up and new compounds may be formed. The new minerals produced are more stable than the original ones and have in general a greater density and consequently a smaller volume. The type of metamorphism that produces these effects is known as *dynamic metamorphism.*

Organic Secretions.—The transfer of mineral substances from a state of solution to the solid condition is often produced through the aid of organisms. Mollusca, like the oyster, clam, etc., crustaceans, like the lobster or crab, the microscopic animals and plants known as pro-

FIG. 5.—Diorite Dike Cutting Granite Gneiss. Pelican Tunnel, Georgetown, Colo. (*After Spurr and Garry.*)

tozoans and algae and many other animals and vegetables abstract mineral matter from the water in which they live and build up for themselves hard parts. These hard parts, usually in the form of external shells, are composed of calcium carbonate ($CaCO_3$), either as calcite or aragonite, of silica (SiO_2) or of calcium phosphate $Ca_3(PO_4)_2$. Although not commonly regarded as minerals these substances are identical with corresponding substances produced by inorganic agencies.[1]

Paragenesis.—It is evident that minerals produced in the same

[1] Plants and animals upon decaying yield organic acids which may attack minerals already existing and thus give rise to solutions which may deposit pyrite (FeS_2), limonite (a hydrated iron oxide) or some other metallic compound. This process, however, is properly simply a phase of deposition from solutions.

way will generally be found together. A certain association of minerals will thus characterize deposits from magmas, another association

FIG. 6.—Vein in Griffith Mine, Georgetown, Colo., Showing Two Periods of Vein Deposition. (*After Spurr and Garry.*)

gn = wall rock. *b* = sphalerite. *c* = chalcopyrite.
q = comb quartz. *p* = pyrite. *g* = galena.

Balance of vein-filling is a mixture of manganese-iron carbonates.

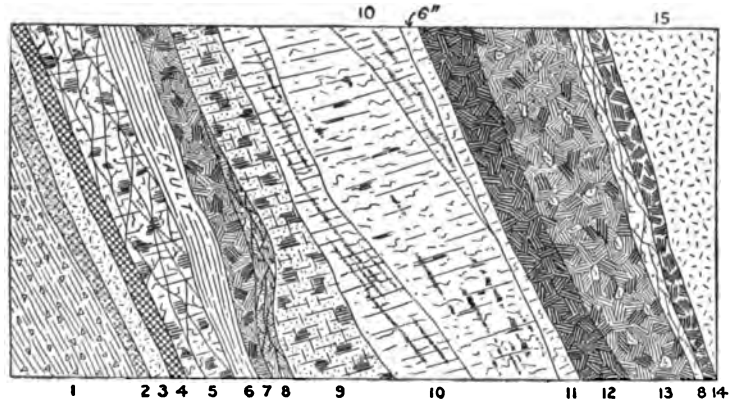


FIG. 7. Vein Forming Original Ore-Body, Butte, Mont. (*After W. H. Weed.*)

(1) Fault breccia; (2) ore; (3) altered granite; (4) first-class ore; (5) crushed quartz and bornite; (6) fault clay; (7) solid pyrite and bornite; (8) crushed quartz and pyrite; (9) solid enargite ore with bornite; (10) banded white quartz and bornite; (11) white quartz, 6 inches; (12) solid bornite; (13) solid pyrite with bornite and quartz blotches; (14) bornite; (15) granite.

those precipitated from water, another those produced by contact action, etc. This association of minerals of a similar origin is known

as their *paragenesis*. From a study of their relations to one another the order of their deposition may usually be determined.

Occurrence.—The manner of occurrence of mineral substance is extremely varied, as may be judged from the consideration of the various ways in which they are formed. Deposits laid down in water occur in beds or in the cement uniting grains of sand, etc., such as the beds of salt (NaCl) or gypsum ($CaSO_4 \cdot 2H_2O$) found in many regions. Those produced by the cooling of magmas may form great masses of rock such as granite, which when it occurs as the filling of cracks in other rocks is said to have the form of a *dike* (Fig. 5). Deposits made by water, whether meteoric or magmatic may give rise to veins, which may be straight-walled or branching, like the veins of quartz (SiO_2) that are so frequently seen cutting various siliceous rocks. When the veins are filled by meteoric water they often have a comb-structure—the filling consisting of several substances arranged in definite layers following the vein walls (see p. 21). If the composition of the depositing solution, whether meteoric or magmatic, has remained constant for a long time the vein may be filled with a single substance. If its composition changed during the time the filling was in progress the layers are of different kinds. Further, if deposition continued uninterruptedly the layers may match on opposite sides of the vein and the succession may be the same from walls to center. If, however, after the partial or complete filling of the crack it was reopened and the new crack was filled, the new vein when filled would be unsymmetrical if the new crack occurred to one side of the center of the original vein (Fig. 6). Repeated reopening may give rise to a vein that is so lacking in symmetry that it is difficult to trace the succession of events by which it was produced (Fig. 7). Veins filled by magmatic water are frequently more homogeneous.

FIG. 8.—Druse of Smithsonite ($ZnCO_3$) on Massive Smithsonite.

Druses (Fig. 8) arise when deposits simply coat the walls of fissures.

In many cases they may be regarded as veins, the development of which has been arrested and never completed. When the deposits coat the walls of hollows within rocks they are known as *geodes* (Fig. 9). Geodes are common in limestones and other easily soluble rocks in which cavities may be dissolved.

Gases and water under great pressure may penetrate the microscopic pores existing in all rocks and there deposit material which may fill the pores and cement the rocks. If the deposited material is metallic the rocks may be transformed into masses sufficiently rich in metallic matter to become ore-bodies. A body of this kind is known as an *impregnation*. It is well represented by some of the low grade gold ores, such as those in the Black Hills.

When rocks are decomposed by the weather they are broken up.

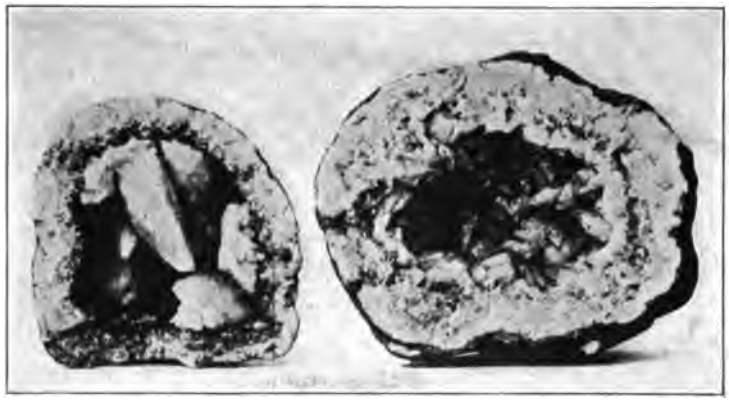


FIG. 9.—Geodes Containing Calcite ($CaCO_3$) Crystals.

The rains wash the disintegrated substance into streams. In its course downward to lakes or the ocean, the heavier fragments, such as metallic particles, may settle while the lighter portions are carried along. Thus the heavy parts may accumulate in the stream bottoms. These materials, consisting of gold, magnetite, garnet, pyrite and other minerals of high specific gravity, form a loose deposit in the stream bed which is known as a *placer*. Gold is often found in placer deposits. The lighter portions may be carried to the lake or sea into which the streams enter and may accumulate as sand on beaches and on the bottom near the shores as gravel, sand, silt, etc. Most sand consists principally of quartz, but many sands contain also grains of feldspar and other silicates, and sometimes other compounds.

Alteration of Minerals.—Minerals, like living things, are constantly subject to change. Circulating waters may dissolve them in part, or completely, and transport their material to a distant place, there depositing it either in the form it originally possessed or in some new form. On the other hand, the mineral substance may be decomposed into several compounds some of which may be carried off, while others are left behind. Again, the material remaining behind may combine with other matter held in the water causing the decomposition, and may form with it a new mineral or a number of different minerals occupying the place of the original one. This is in part metasomatism.

The atmosphere may also act as a decomposer of minerals. Through the agency of its oxygen it may cause their oxidation, or it may cause them to break up into several oxidized compounds. Through the agency of its moisture, it may dissolve some of these secondary substances or it may form with them hydrated compounds. The substances thus formed may be dissolved in water and carried off, or they may remain to mark the place of the mineral from which they were derived.

Water, containing traces of salts, or gases in solution are exceedingly active agents in effecting changes in minerals. Many examples of the alteration of practically insoluble minerals under the influence of dilute solutions are known. Calcite ($CaCO_3$), for instance, when acted upon by a solution of magnesium chloride ($MgCl_2$) takes up magnesium and loses some of its calcium. Monticellite ($CaMgSiO_4$) when acted upon by solutions of alkaline carbonates breaks up into a magnesium silicate and calcium carbonate. Dilute solutions of various salts are constantly circulating through the earth's crust and are there effecting transformations in the minerals with which they come in contact. On, or near, the surface the transformations are taking place more rapidly than elsewhere because here the solutions are aided in their decomposing action by the gases of the atmosphere.

The effect of the air in causing alteration is seen in the green coating of malachite ($(CuOH)_2CO_3$) that covers surfaces of copper or of copper compounds exposed to its action. In this particular case the coating is due to the action of the carbon dioxide and the moisture of the atmosphere. Other substances in contact with the air are coated with their own oxides, sulphides, etc.

Pseudomorphs.—When the alteration of a mineral has proceeded in such a manner that the new products formed have replaced it particle by particle a *pseudomorph* results. Sometimes the newly formed substance crystallizes as a single homogeneous grain filling the entire space occupied by the original substance. Usually, however, the alter-

ation begins along the surfaces of cracks or fissures in the body undergoing alteration, or upon its exterior, thus producing the new material at several places contemporaneously (Fig. 10). When the replacement takes place in this manner the resulting mass is a network of fibers of the new substance or an aggregate of grains with the outward form of the replaced mineral.

With respect to their method of formation chemical pseudomorphs may be classified as alteration pseudomorphs and replacement pseudomorphs.

Alteration Pseudomorphs. — Pseudomorphs of this class may be defined as those which retain some or all of the constituents of the original minerals from which they were derived.

Paramorphs. — Pseudomorphs composed of the material of the pseudomorphed substance without addition or subtraction of any component are known as *paramorphs.*

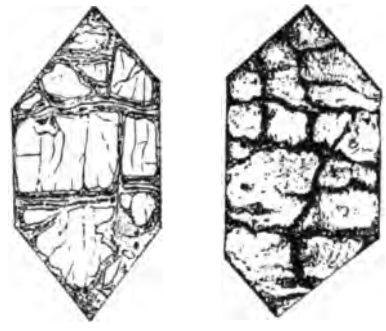


FIG. 10.—Alteration of Olivine into Serpentine. The alteration is proceeding from the surface of the crystal and from surfaces of cracks that traverse it. The black specks and streaks represent magnetite formed during the process. (*After Tschermak.*)

Paramorphism is possible only in the case of dimorphous bodies. It results from the rearrangement into new bodies of the particles of which the original body was composed.

Illustrations: *Calcite* (hexagonal $CaCO_3$) after aragonite (orthorhombic $CaCO_3$); orthorhombic sulphur after the monoclinic variety.

Partial Pseudomorphs.—The great majority of pseudomorphs retain a portion, but not all, of the material of the original mineral. They may be formed by the addition of material to the original body; by the loss of material from it; or by the replacement of a portion of its material by new material.

Pseudomorphs formed by the addition of substance to that already existing are rare. The substances most frequently added in the production of such pseudomorphs are oxygen, sulphur, the hydroxyl group (OH) and the carbonic acid group (CO_3 and CO_2).

Illustrations: *Malachite* ($(CuOH)_2CO_3$) after *copper*, and *argentite* (Ag_2S) after *silver*.

Pseudomorphs resulting from the loss of material are not common.

They are caused by the abstraction of one or more of the constituents of a compound.

Illustration: *Native copper* after *cuprite* (Cu_2O).

The greater number of partial pseudomorphs are formed by the substitution of some of the components of the original mineral by a new material.

Illustrations: *Limonite* ($Fe_4O_3(OH)_6$) pseudomorphs after *siderite* ($FeCO_3$) may be formed by the following reaction:

$$4FeCO_3+2O+3H_2O=4CO_2+Fe_4O_3(OH)_6.$$

Cerussite ($PbCO_3$) may be formed from *galena* (PbS), thus:

$$PbS+4O+Na_2CO_3=PbCO_3+Na_2SO_4.$$

Replacement Pseudomorphs.—Often the entire substance of a mineral is replaced by new material, so that no trace of its original matter remains. In this case the nature of the pseudomorphed mineral can be discovered only from the form of the pseudomorph.

Illustrations: *Quartz* (SiO_2) after *calcite* ($CaCO_3$) and *gypsum* ($CaSO_4 \cdot 2H_2O$) after *halite* ($NaCl$).

Mechanical Pseudomorphs.—The processes described above as originating pseudomorphs are chemical, and the resulting pseudomorphs are sometimes designated *chemical pseudomorphs*. There is another class of pseudomorphs, however, in which the substance of a crystal has not been replaced gradually by the pseudomorphing substance. In this class the pseudomorphing substance simply fills a mold left by the solution of some preëxisting crystal. Thus, if a sulphur crystal should become encrusted with a coating of barite ($BaSO_4$) and the temperature should rise until the sulphur melts and escapes, there would be left a mold of itself constructed of barite. If, now, a solution of calcium carbonate should penetrate the cavity and fill it with a deposit of calcite ($CaCO_3$), the mass of calcite would have the shape of a crystal of sulphur. Pseudomorphs of this kind are known as *mechanical pseudomorphs*.

Weathering.—The term *weathering* is applied to the sum of all the changes produced in minerals by the action of the atmosphere upon them. Although nearly all minerals show some traces of weathering, these traces may often be detected only by the slight differences in color exhibited by surfaces that have been exposed for a long time to the action of the air when compared with fresh surfaces produced by fracture or cleavage.

The weathering of minerals is often of great economic importance. Veins of sulphides and a few other compounds may be oxidized where they outcrop on the surface. Some of the decomposition products thus formed may be soluble and others insoluble. The insoluble products may remain near the surface while the soluble ones are carried downward by ground water along the course of the vein. Here a reaction may ensue between the soluble salts and the undecomposed portion of the vein with the result that metallic compounds may be precipitated, thus enriching the original vein matter and causing it to be changed from a comparatively lean ore to one of great richness.

Pyrite veins on the surface are often marked by accumulations of limonite derived by the oxidation of the sulphide. With this may be mixed insoluble carbonates, silicates and other salts of valuable metals present in the original sulphide. Weathering may extend downward along the veins for a short distance, replacing their upper portions with the oxidized decomposition products. This portion of a vein is often spoken of as the *oxidized zone*, and this is sometimes the richest portion of the vein. It may be rich because less valuable substances have formed soluble salts and have been drained away.

Below the oxidized zone may be another zone less rich in valuable compounds than the oxidized zone, but much richer than the material below it. The soluble decomposition products of the upper portion of the vein may percolate downward, and react with the unchanged vein matter, precipitating valuable metallic salts. Although the original vein matter may contain an inconsiderable quantity of the valuable material, the precipitation in it of additional stores of material of the same kind may raise the percentage of this constituent to a point where it is profitable to mine it. This belt of enriched ore is known as the *zone of secondary enrichment.*

The oxidized zone extends downward from the surface to a depth at which the atmosphere and meteoric water become exhausted of their oxygen—a depth which varies with local conditions. The zone of secondary enrichment extends from the bottom of the oxidized zone to a short distance below the level of the ground water, beyond which solutions will diffuse and thus be carried away from the vein. Below the zone of enrichment the original vein-filling may reach downward indefinite distances.

Since many veins exhibit the features described, it follows that the ore of many mines must grow poorer with depth, and that in many instances the richest ore is near the surface.

Some of the changes involved in weathering and secondary enrich-

ment of sulphide veins in limestone are indicated by the following reactions in the case of a vein containing pyrite (FeS_2), sphalerite (ZnS), and galena (PbS).

(1) The first change produced at the surface may be the oxidation of the sulphides to sulphates.

(*a*) $ZnS+4O=ZnSO_4$;
(*b*) $PbS+4O=PbSO_4$ (anglesite);
(*c*) $FeS_2+7O+H_2O=H_2SO_4+FeSO_4$.

(2) These may react with the limestone as follows:

(*a*) $ZnSO_4+CaCO_3+2H_2O=\underset{\text{(smithsonite)}}{ZnCO_3}+\underset{\text{(gypsum)}}{CaSO_4\cdot 2H_2O}$;

(*b*) $PbSO_4+CaCO_3+2H_2O=\underset{\text{(cerussite)}}{PbCO_3}+\underset{\text{(gypsum)}}{CaSO_4\cdot 2H_2O}$.

(3) Some of the sulphates and carbonates carried down into the unaltered sulphides may react with these, yielding:

(*a*) $PbSO_4+FeS_2+O_2=\underset{\text{(galena)}}{PbS}+FeSO_4+SO_2$;

(*b*) $PbCO_3+FeS_2+O_2=\underset{\text{(galena)}}{PbS}+\underset{\text{(siderite)}}{FeCO_3}+SO_2$;

(*c*) $PbSO_4+ZnS=\underset{\text{(galena)}}{PbS}+ZnSO_4$;

(*d*) $PbCO_3+ZnS=\underset{\text{(galena)}}{PbS}+\underset{\text{(smithsonite)}}{ZnCO_3}$.

The PbS replacing the ZnS and deposited in the cracks in the original mixture of PbS, ZnS and FeS_2 increases the percentage of this compound in the vein and thus enriches it.

There is also an increase in the percentage of ZnS brought about by the reactions between the zinc salts (1*a* and 2*a*), and the pyrite, analogous to those between the lead salts and pyrite (3*a* and 3*b*). Thus:

$$ZnSO_4+FeS_2+O_2 = \underset{\text{(sphalerite)}}{ZnS} + FeSO_4+SO_2,$$

$$ZnCO_3+FeS_2+O_2 = \underset{\text{(sphalerite)}}{ZnS} + FeCO_3+SO_2.$$

The zinc salts produced in reactions *3c* and *3d* if carried downward will also have the opportunity to react with the pyrite in the same way.

If the ZnS is deposited in fissures in the vein matter this will tend to enrich it with zinc.

The oxidized zone contains (smithsonite) $ZnCO_3$, (anglesite) $PbSO_4$, (cerussite) $PbCO_3$ and (limonite) $Fe_2(OH)_2$. The $ZnSO_4$, formed also in the oxidized zone, is so readily soluble in water that it is leached from the other oxidized compounds and is carried downward.

PART II

DESCRIPTIVE MINERALOGY

CHAPTER III

INTRODUCTION—THE ELEMENTS

Of the 1,000 or more distinct minerals recognized by mineralogists only a few (some 250) are common. A few are important because they constitute ores, others because they are components of rock masses, and others simply because of their great abundance. Only a few mineralogists profess acquaintance with more than 500 or 600 minerals. The majority are familiar with but 300 or 400, relying for the identification of the remainder upon the descriptions of them recorded in mineralogical treatises.

Only the minerals commonly met with and those of economic or of special scientific importance are described in this book. They should be studied with specimens before one, in order that the relation between the descriptions and the objects studied may be forcibly realized. Mineralogy cannot be studied successfully from books alone. It is primarily a study of objects and consequently the objects should be at hand for inspection.[1]

Mineral Names.—The names of the great majority of minerals end in the termination "ite." This is derived from the ancient Greek suffix "itis" which was always appended to the names of rocks to signify that they are rocks. The first portion of the name, to which the suffix is added, either describes some quality or constituent possessed by the mineral, refers to some common use to which it has been put, indicates the locality from which it was first obtained, or is the name of some person intended to be complimented by the mineralogist who first described the mineral bearing it.

[1] Collections of the common minerals in specimens large enough for convenient study may be secured at small cost from any one of the mineral dealers whose addresses may be found in any mineralogical journal.

The following examples taken from Dana illustrate some of these principles. The mineral *hematite* (Fe_2O_3) is so named because of the red color of its powder, *chlorite* (a complicated silicate), because of its green color, *siderite* ($FeCO_3$), from the Greek word for iron, because it contains this metal, *magnetite* (Fe_3O_4) after Magnesia in Asia, *goethite* ($FeO(OH)$) after the poet Goethe.

The names of a few minerals end in "ine," "ane," "ase," "ote," etc., but the present tendency is to have them all end in "ite." Occasionally, the same mineral may have two names. This may be due to the fact that it was discovered by two mineralogists working at the same time in different places, or it may be due to the fact that the mineralogists of different countries prefer to follow different precedents set by the old mineralogists of their respective nationalities. For example, the mineral $(Mg \cdot Fe)_2SiO_4$ is called *olivine* by the Germans and by most English-speaking mineralogists, and *peridot* by the French. The Germans follow the German mineralogist Werner, who first used the name olivine in 1789, while the French follow the French teacher Haüy, who proposed the name peridot in 1801.

ELEMENTS

The elements that occur in nature are few in number, and these, with rare exceptions, do not occur in great abundance. They may be separated into the following groups: the carbon group, the sulphur group, the arsenic group, the silver group, and the platinum-iron group. Some of these comprise only a single mineral, while others comprise six or seven. Only a portion of these are described.

THE NON-METALS AND METALLOIDS

CARBON GROUP

The carbon group embraces several minerals of which one is *diamond*, another is an amorphous black substance known as *schungite*, and the other two are apparently but different forms of *graphite*. The element may thereupon be regarded as trimorphous. Diamond and graphite are both important.

Isometric (hextetrahedral)	Hexagonal (ditrigonal scalenohedral)
Diamond	Graphite

Diamond (C)

The diamond is usually found in distinct crystals or in irregular masses, varying in size from a pin's head to a robin's egg. In some cases large individual pieces are found but they are exceedingly rare.

The largest ever found, known as the Cullinan diamond (Fig. 16), weighed 3,024¾ carats or 621 grams, or 1.37 lb., and measured 112×64×51 mm. It was cut into nine fine gems and a number of smaller ones (Fig. 17).

FIG. 11.—Etch Figures on Cubic Face of Diamond Crystal. (*After Tschermak.*)

In composition the diamond is pure carbon, but it is a form of carbon that is not ignited and burned at low temperatures. At high temperatures, however, especially when in the presence of oxygen, it burns freely with the production of CO_2, and, in the case of opaque varieties, a little ash.

Its crystallization is isometric (hextetrahedral class), and the forms on the crystals often appear to be tetrahedrally hemihedral, although the etch figures on cubic faces suggest hexoctahedral symmetry (Fig. 11). Octahedrons, tetrahedrons, icositetrahedrons and combinations of these forms are common, and in nearly all cases the interfacial edges are rounded and the crystal faces curved. Sometimes this curving is so pronounced that the individuals are practically spheres (Fig. 12). Twins are common with O(111) as the twinning plane (Fig. 13).

FIG. 12.—Crystal of Diamond with Rounded Edges and Faces. (*Krantz.*)

The cleavage of diamond is perfect parallel to the octahedral face. This is an important characteristic, as the lapidary makes use of it in the preparation of stones for cutting. Its fracture is conchoidal. Its specific gravity is 3.52 and its hardness greater than that of any other known substance. Most diamonds are dark and opaque, or, at most, translucent, but many are found that are transparent and colorless or nearly so. Gray, brown, green, yellow, blue and red tinted stones are also known, and, with the exception of the blue and red diamonds, these are more common than the colorless, or so-called white stones. The luster of all diamonds is adamantine, and

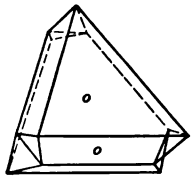


FIG. 13.—Octahedron of Diamond Twinned about O(111).

their index of refraction is very high, $n = 2.4024$ for red rays, 2.4175 for yellow rays, and 2.4513 for blue rays. In consequence of their strong dispersion, the reflection of light from the inner surfaces of transparent stones is very noticeable, causing them to sparkle brilliantly, with a handsome play of colors. It is this latter fact and the great hardness of the mineral that make it the most valuable of the gems. The mineral is a nonconductor of electricity.

Three varieties of the diamond have received distinct names in the trade. These are:

Gem diamonds, which are the transparent stones;

Bort, or *Bortz*, gray or black translucent or opaque rounded masses, with a rough exterior and the structure of a crystalline aggregate; and

Carbonado, black, opaque or nearly opaque masses possessing a crystalline structure, but no distinct cleavage.

The only minerals with which diamond is liable to be confused are much softer, and, consequently, there is little difficulty in distinguishing between them.

Syntheses.—Small diamonds have been made by fusing in an electric furnace metallic iron containing a small quantity of carbon and cooling the mass suddenly in a bath of molten lead. They have also been made by heating in the electric arc pulverized carbon on a spiral of iron wire immersed in hydrogen under a pressure of 3,100 atmospheres. A third method, which resulted in the production of tiny octahedrons, consisted in melting graphite in olivine, or in a mixture of silicates having the composition of the South African "blue ground," with the addition of a little metallic aluminium or magnesium.

Occurrence and Origin.—Diamonds are found (1) in clay, sand or gravel deposits or in the rocks formed by the consolidation of these substances, where they are associated with gold, platinum, topaz, garnet, tourmaline and with other minerals that result from the decomposition of granitic rocks, (2) in a basic igneous rock containing fragments of shale (a consolidated mud) and (3) small diamonds have been discovered in meteorites.

The manner of origin of diamonds has been a subject of controversy for many years. The most popular theory ascribes the diamonds in igneous rocks to the solution of organic matter in the rock magmas and the crystallization of the carbon upon cooling. Another theory regards the carbon as an original constituent of the magma. The diamonds in sand, sandstone, granite, etc., are believed to have been transported from their original sources and deposited in river channels or on beaches.

Localities.—The principal localities from which diamonds are obtained are the Madras Presidency in India; the Province of Minas-Geraes in Brazil; the Island of Borneo; the valleys of the Vaal and Orange Rivers, and other places in South Africa, and the valley of the Mazaruni River and its tributaries in British Guiana. Recently diamond fields have been discovered in New South Wales, Australia, in the valley of the Kasai River in the Belgian Kongo, in Arkansas, and in the Tulameen district, British Columbia.

In the United States a few gem diamonds have been found from time to time in Franklin and Rutherford counties in North Carolina; in the gold-bearing gravels of California, and in soils and sands in the states of Alabama, Virginia, Wisconsin, Indiana, Ohio, Idaho and Oregon. A stone (the Dewey diamond) found near Richmond, Virginia, a few years ago is valued at $300 or $400.

The principal source of diamonds and carbonado in Brazil at the present time is Bahia, where the mineral occurs in a friable sandstone along river courses. The output of this region has decreased so greatly in the last few years that although a mass of carbonado weighing 3,073 carats (the largest mass of diamond material ever found) was obtained in 1895, the price of this impure diamond rose from $10.50 per carat in 1894 to $36.00 per carat in 1896 and $85.00 per carat for the best quality in 1916.

The only diamond field of prominence in the United States is that which has recently been exploited near Murfreesboro in Arkansas, where the conditions are similar to those existing in South Africa. The diamonds occur in a basic igneous rock (peridotite) that cuts through sandstones and quartzites. The peridotite is weathered to a soft earth or "ground" in which the diamonds are embedded. Up to the end of 1914 over 2,000 diamonds had been found, mostly small stones weighing in the aggregate 550 carats, valued at about $12,000. One, however, weighed 8½ carats and another 7½ carats. The rough unsorted stones are valued at $10 per carat. Three stones that were cut were found to be worth from $60 to $175 per carat. The district has not yet been sufficiently developed to prove its commercial value. The diamonds in British Columbia occur in the same kind of rock as those in Arkansas. The few that have thus far been found are too small for any practical use.

In former times the mines of India and Borneo were very productive, the famous Golconda district in India for a long period furnishing most of the gems to commerce.

The African mines were opened in 1867. Since this time they

have been practically the only producers of gem material in the world. It is estimated that the quantity of uncut diamonds yielded by the mines near Kimberly alone have amounted in value to the enormous sum of $900,000,000. The output of the African mines in 1913 was sold for about $53,000,000, being over 95 per cent of the world's output of gem material. Of this amount about $9,000,000 worth of stones were furnished by German Southwest Africa, the balance by the Union of South Africa. The diamonds are found in a peridotite which occurs in the form of volcanic necks, or "pipes," cutting carbonaceous shales. The igneous rock is much weathered to a soft blue earthy mass known as "blue earth." Near the surface where exposed to the action of the atmosphere the earth is yellow. The diamonds are scattered through the weathered material in quantities amounting to between .3 and .6 carat per cubic yard.

Extraction.—Where the diamond occurs in sand and gravel it is obtained by washing away the lighter substances.

In South Africa and Arkansas the mineral is found in a basic volcanic rock which weathers rapidly on exposure to the air. The weathered rock is mined and spread on a prepared ground to weather. When sufficiently disintegrated water is added to the mass and the mud thus formed is allowed to pass over plates smeared with grease. The diamonds and some of the other materials adhere to the grease, but most of the valueless material is carried off by the water.

Uses.—Transparent diamonds constitute the most valuable gems in use. Perfectly white stones, or those possessing decided tints of red, rose, green or blue are the most highly prized. They are sold by weight, the standard being known as the carat, which, until recently, was equivalent to 3.168 grains or 205 milligrams. At present the metric carat is in almost universal use. This has a weight of 200 milligrams. The price of small stones depends upon their color, brilliancy and size—a perfectly white, brilliant, cut stone weighing one carat, being valued at about $175.00. As the size increases the value increases in a much greater ratio, the price obtained for large stones depending almost solely upon the caprice of the purchaser.

Nearly all the gem diamonds put upon the market are cut before being offered for sale. The chief centers of diamond cutting are Antwerp and Amsterdam in the Old World and New York in America. The favorite cuts are the brilliant and the rose. For the former only octahedral crystals, or those that will yield octahedrons by cleavage, are used, for the rose cut distorted octahedrons or twinned crystals. In producing the "brilliant" a portion of the top of an octahedron is cut

off and a small portion of the bottom. On the remainder are cut three or four bands of facets running horizontally around the stone (see Fig. 14). The "rose" has a flat base surmounted by a pyramidal dome consisting of 24 or more facets. In late years the shapes into which diamonds are cut have been determined less by the decrees of fashion and more by the desire to save as much material as possible, and, consequently, irregularly shaped cut diamonds are much more common than formerly (compare Fig. 17).

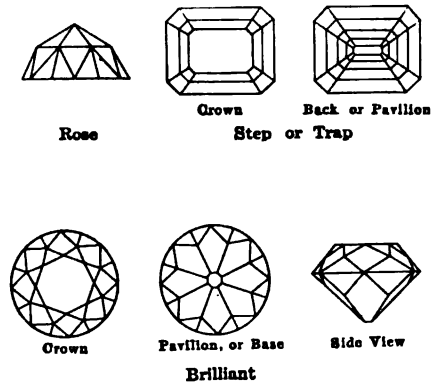


FIG. 14.—Principal " cuts " of Diamonds.

Diamonds are employed also as cutting tools. Small fragments, or splinters of gem quality, are used for cutting and polishing diamonds and other gems, and small crystals with crystal edges for cutting glass. Small cleavage pieces are utilized in the manufacture of engravers' tools and writing instruments. Recently diamonds with small holes of from .008 to .0006 of an inch drilled in them, have been employed as wire dies.

Bort is also used as a polishing and cutting material, while carbonado, nearly all of which comes from Brazil, is used in the manufacture of boring instruments. Diamond drills consist of hollow cylinders of soft iron set at their lower edges with 6, 8 or 12 black diamonds. By rapid revolution of this a "core" may be cut from the hardest rocks.

Some Famous Diamonds.—The largest diamond ever found—the Cullinan—was picked up at the Premier Mine (Fig. 15) in the Transvaal in January, 1905, and was presented to King Edward of England as a birthday gift in 1908. (Figs. 16 and 17.) It weighed about 3,025 carats (about 1.37 pounds). The next largest was found in June, 1893, at the Jagersfontein mine. It is known as the Excelsior. It weighed in its natural state 971 carats and was 3 inches long in its greatest dimension. It was valued at $2,000,000. It is said to have been presented by the President of The Orange Free State to Pope Leo XIII. The third largest stone is the Reitz. It is a 640-carat stone found at the same mine during the close of 1895. This, though smaller, is said to be handsomer than the Excelsior. The most noted diamond in the world is the Kohinoor, which weighed, before cutting, 186 carats. It is now a brilliant of 106 carats, belonging to the crown of England. Other famous diamonds are the

FIG. 15.—Premier Diamond Mines in South Africa. (*After Williams.*)

FIG. 16.—The Cullinan Diamond. (Natural size.)

FIG. 17.—Gems Cut from the Cullinan Diamond. (Two-fifths nat. size.)

Orlov, 193 carats, the property of Russia; the Regent or Pitt diamond of 137 carats belonging to France; the Green diamond of Dresden, weighing 48 carats, and the Blue Hope diamond, weighing 44 carats. The "Star of the South," found in Brazil, weighed 254 carats before cutting and 125 afterward. The Victoria diamond from one of the Kimberly mines weighed 457 carats when found. It has been cut to a perfect brilliant of 180 carats valued at $1,000,000. The Tiffany diamond (Fig. 18) now owned in New York is a double brilliant of a golden yellow color weighing 128½ carats (25.702 grams) and valued at $100,000. When it is remembered that a five-carat stone is large, the enormous proportions of the above-named gems are better appreciated.

FIG. 18.—The Tiffany Diamond. (Natural size.) (*Kindness of Tiffany & Co.*)

Graphite (C)

Graphite, or plumbago, occurs principally in amorphous masses of a black, clayey appearance, in radiated masses, in brilliant lead black scales or plates, and occasionally in crystals with a rhombohedral habit.

Like diamond, graphite consists of carbon. Crystals from Ceylon yield: C=79.40; Ash=15.50; Volatile matter=5.10. The mineral is often impure from admixture with clay, etc.

Crystals of the material are so rare that their symmetry is still in doubt. Their habit is hexagonal (ditrigonal scalenohedral class). Measurements made on the interfacial angles of crystals from Ticonderoga, New York, gave $a : c = 1 : 1.3859$. These possess a rhombohedral symmetry. All crystals are tabular and nearly all are so distorted that the measurements of their interfacial angles cannot be depended upon for accuracy. They apparently contain the planes $R(10\bar{1}1)$; $oP(1000)$; $\infty P2(11\bar{2}0)$, and $2P2(11\bar{2}1)$.

Graphite is black and earthy, or lustrous, according as it is impure or pure. It is easily cleavable parallel to the basal plane, and the cleavage laminae are flexible. It is very soft, its hardness being only 1–2, its density about 2.25. Its luster is metallic and the mineral is opaque even in the thinnest flakes. It is a conductor of electricity.

Graphite is infusible and noncombustible even at moderately high temperatures. Like diamond, however, it may be burned under certain conditions at very high temperatures (650°–700°). It is unaffected by the common acids and is not acted upon by the atmosphere. When, however, it is subjected to the action of strong oxidizing agents, such as a warm mixture of potassium chlorate ($KClO_3$) and fuming nitric acid, it changes to a yellow substance known as graphitic acid ($C_{11}H_4O_5$). It is thus distinguished from amorphous carbon, like *schungite* and *anthracite*. Moreover, many forms of graphite, when moistened with fuming nitric acid and heated, swell up and send out worm-like processes. Those which do not act thus are called *graphitite*. Natural graphite is of both types.

Its color, softness and infusibility serve to distinguish graphite from all other minerals but *molybdenite* (p. 75). It may be distinguished from this mineral by the fact that it contains no sulphur.

Syntheses.—Crystalline graphite is made on a commercial scale by treating anthracite coal or coke containing about 5.75 per cent of ash in an electric furnace. It also separates when molten iron containing dissolved carbon is cooled.

Occurrence and Origin.—Graphite occurs as thin plates and scales in certain igneous rocks, in gneisses, schists and limestones, as large scales in coarse granite dikes (pegmatite) and in crystalline limestones, and as amorphous masses at the contacts of igneous rocks with carbonaceous rocks. The mineral is also found in veins cutting sedimentary and metamorphic rocks. Crystals are found only in limestone.

The occurrence of graphite in sedimentary and igneous rocks suggests that it may have been formed in several ways. It is thought that the material in limestone and quartz-schist may represent carbo-

naceous material that was deposited with the sediments and which has since been carbonized by heat and pressure. The material in pegmatite may be an original constituent of the magma that produced the rock, and the graphite may be the product of pneumatolytic processes; i.e., it may have been produced by deposits from vapors that accompanied the formation of the pegmatite. If this be true, the mineral found in metamorphosed limestone and schist may be of contact origin; i.e., it may have been produced by the migration of gases and solutions from igneous rocks into the mass of the surrounding sediments. The vein deposits probably had a similar origin, the mineral having been deposited mainly in cracks traversing metamorphic rocks. On the other hand, graphite, in some instances, appears to be a direct separation from a molten magma.

Localities.—The principal foreign source of supply for commercial graphite is the Island of Ceylon. In the United States the mineral has been mined on the southeast side of the Adirondacks in New York; in Chester County, Pennsylvania; near Dillon, Montana; at several points in Arkansas, Georgia, Alabama and North Carolina; in Wyoming; in Baraga County, Michigan, and to a small extent in Colorado, Nevada, and Wisconsin. It occurs also abundantly at many other places. Its chief source in the United States is Graphite, near Lake George, New York.

Preparation.—Graphite is obtained on a commercial scale by grinding the rock containing it and floating the graphite flakes.

Uses.—Crude graphite, or plumbago, is used in the manufacture of stove and other polishes, and of black paint for metal surfaces, for both of which it is especially valuable on account of its noncorroding properties. The purified mineral is mixed with clay and made into crucibles for use at high temperatures. It is also ground and used in this form as a lubricant for heavy machinery, and is compressed into " black lead " centers for lead pencils.

Production.—The quantity of crude graphite mined in the United States during 1912 amounted to 2,445 tons, valued at $207,033, besides which there were manufactured 6,448 tons, valued at $830,193. The imports were 25,643 tons, valued at $709,337.

Schungite is a black, amorphous carbon with a hardness of 3–4 and a sp.gr. of 1.981. It is soluble in a mixture of HNO_3 and $KClO_3$ without the production of graphitic acid. It occurs in some crystalline schists.

SULPHUR GROUP

Sulphur is known in at least six different forms, four of which are crystalline. The two best known forms crystallize respectively in the orthorhombic (orthorhombic bipyramidal class) and the monoclinic (prismatic class) systems. The former separates from solutions of sulphur in carbon bisulphide and the latter separates from molten masses. Both the orthorhombic and the monoclinic phases are believed to be formed by natural processes, but the latter passes over into the former upon standing, so that its existence as a mineral cannot be definitely proven. *Selenium* and *tellurium*, which are also members of the sulphur group, are extremely rare. Tellurium occurs in rhombohedral crystals and selenium in mixed crystals of doubtful character with sulphur and tellurium.

Sulphur (S)

Sulphur occurs in nature as a lemon-colored powder, as spherical or globular masses, as stalactites and in crystals.

Chemically it is pure sulphur, or a mixture of sulphur and clay,

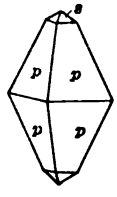
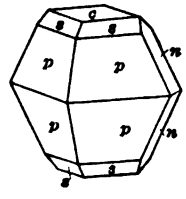


FIG. 19.



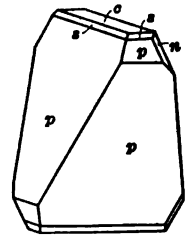


FIG. 20.

FIG. 19.—Sulphur Crystals with P, 111 (*p*); 3P, 113 (*s*); P$\breve{\infty}$, 011 (*n*), and oP, 001 (*c*).

FIG. 20.—Distorted Crystal of Sulphur. (Forms same as in Fig. 19.)

bitumen or other impurities. It sometimes contains traces of tellurium, selenium and arsenic.

Crystals of sulphur are usually well formed combinations of orthorhombic bipyramids and domes, with or without basal terminations. Their axial ratio $=.8108 : 1 : 1.9005$. The principal forms observed are P(111), P$\bar{\infty}$ (101), P$\breve{\infty}$ (011), $\frac{1}{3}$P(113) and oP(001) (Figs. 19 and 20). The habit of the crystals is usually pyramidal, though crystals with a tabular habit are quite common.

Crystals of sulphur are yellow. Their streak is light lemon yellow.

The mineral has a resinous luster. Its hardness is only 1.5–2, and density about 2.04. Its fracture is conchoidal and cleavage imperfect. It is transparent or translucent, is brittle and is a nonconductor of electricity. Its indices of refraction for sodium light are $\alpha = 1.9579$, $\beta = 2.0377$, $\gamma = 2.2452$.

Massive sulphur varies in color from yellow to yellowish brown greenish gray, etc., according to the character and amount of impurities it contains. Its powder is nearly always crystalline. In mass it possesses a lighter color than the crystals or the massive sulphur.

At a temperature of 114° sulphur melts, and at 270° it ignites, burning with a blue flame and evolving fumes of SO_2. At about 97° it passes over into the monoclinic phase. It is insoluble in water and acids, but is soluble in oil of turpentine, carbon bisulphide and chloroform.

There are few minerals that are apt to be mistaken for sulphur. From all of them it may be distinguished by its brittleness and by the fact that it melts readily and burns with a nonluminous blue flame.

Syntheses.—Crystals with the form of the mineral are produced by the evaporation of solutions of sulphur in carbon bisulphide, and also by sublimation from the fumes of ore roasters.

Occurrence and Origin.—Sulphur occurs most abundantly in regions of active or extinct volcanoes, and in beds associated with limestone and gypsum ($CaSO_4 \cdot 2H_2O$). In volcanic regions it is produced by reactions between the gases emitted from the volcanoes, or by the reactions of these with the oxygen of the air (see p. 18). The deposits in gypsum beds may result from reduction of the gypsum by organic matter. Sulphur is formed also as a decomposition product of sulphides.

In Iceland and other districts of hot springs sulphur is often deposited in the form of powder as the result of reactions similar to those that take place between the gases of volcanoes. These hot springs are always connected with dying volcanoes, being frequently but the closing stages of their existence.

Localities.—The localities at which sulphur is known to exist are very numerous. Those of commercial importance are Girgenti in Sicily, Cadiz in Spain, Japan; and in the United States, at the geysers of the Napa Valley, Sonoma County, and at Clear Lake, Lake County, California; at Cove Creek, Millard County, Utah; at the mines of the Utah Sulphur Company in Beaver County, in the same State; at Thermopolis, Wyoming, and at various hot springs in Nevada. The mineral occurs also abundantly in the Yellowstone National Park, but cannot be placed on the market because of high transportation charges.

Its principal occurrence in the United States is at Lake Charles in Calcasieu Parish, La., where it impregnates a bed of limestone at a depth of from 450 to 1,100 feet. It occurs also abundantly in the coastal districts of Texas. Here it is associated with gypsum.

Extraction.—Sulphur, when mined, is mixed with clay, earth, rock and other impurities. Until recently it was purified by piling in heaps and igniting. A portion of the sulphur burned and melted the balance, which flowed off and was caught. A purer product is obtained by distillation. "Flowers of Sulphur" are made in this way. At present much of the sulphur is extracted by treating the impregnated rock in retorts with steam under a pressure of 60 pounds and at a temperature of 144° C. The sulphur melts and flows to the bottom of the retorts from which it is drawn off.

In Louisiana and Texas, superheated steam is forced downward into the sulphur-impregnated rocks. This melts the sulphur, which constitutes about 70 per cent of the rock mass. The melted sulphur is forced to the surface and caught in wooden bins. The crude material has a guaranteed content of over 99½ per cent sulphur.

Uses.—Sulphur, or brimstone, is used in the manufacture of some kinds of matches, in making gunpowder, and in vulcanizing rubber to increase its strength and elasticity. It is used extensively in the manufacture of sulphuric acid, but is rapidly giving way to pyrite for this purpose. It is also utilized for bleaching straw, in the manufacture of certain pigments, among which is vermilion, and in the preparation of certain medicinal compounds.

Production.—Most of the domestic product is at present from the Calcasieu Parish, La., where about 300,000 tons are mined annually. New mines have been opened near Thermopolis in Wyoming, in Brazoria County, Texas, and at Sulphur Springs, Nevada. The total amount of the mineral mined in 1912 was 303,472 tons, valued at $5,256,422. Besides, there were imported about 29,927 tons valued at $583,974, most of which came from Japan. Sicily is the largest producer of the mineral, extracting about 400,000 tons annually.

ARSENIC GROUP

The arsenic group comprehends *metallic arsenic*, *antimony*, *bismuth* and (according to some mineralogists), *tellurium*, besides compounds of these metals with each other. They all crystallize in the rhombohedral division of the hexagonal system (ditrigonal scalenohedral class). The only members of the group that are at all common are arsenic and antimony.

Arsenic (As)

Arsenic is rarely found in crystals. It usually occurs massive or in botryoidal or globular forms.

Specimens of the mineral are rarely pure. They usually contain some antimony, and traces of iron, silver, bismuth, and other metals.

The crystals are cubical in habit, with an axial ratio of 1 : 1.4025. The principal forms observed are: $0R(0001)$, $R(10\bar{1}1)$, $\frac{1}{4}R(10\bar{1}4)$, $-\frac{1}{2}R(01\bar{1}2)$ and $-\frac{3}{2}R(03\bar{3}2)$. Twins are rare, with $-\frac{1}{2}R(01\bar{1}2)$ the twinning plane.

Arsenic is lead-gray or tin-white on fresh fractures, and dull gray or nearly black on surfaces that have been exposed for some time to the atmosphere.

Crystals cleave readily parallel to the base. The fracture of massive pieces is uneven. The mineral is brittle. Its hardness is 3.5 and its density 5.6–5.7. Its streak is tin-white tarnishing soon to dark gray. It is an electrical conductor.

Arsenic may easily be distinguished from nearly all other minerals, except antimony and some of the rarer metals, by the color of its fresh surfaces. From these, with the exception of antimony, it is also readily distinguished by its action on charcoal before the blowpipe, when it volatilizes completely without fusing, at the same time tingeing the flame blue and giving rise to dense white fumes of As_2O_3, which coat the charcoal. The fumes of arsenic possess a very disagreeable and oppressive odor, while those of antimony have no distinct odor.

Syntheses.—Arsenic has been obtained in crystals by subliming arsenic compounds protected from the air. It has also been obtained in the wet way by heating realgar (As_2S_3) with sodium bicarbonate at 300° C.

Occurrence and Origin.—Arsenic often accompanies ores of antimony, silver, lead and other metals in veins in crystalline rocks, especially in their upper portions, where it was formed by reduction from its compounds.

Localities.—The silver mines at Freiberg and other places in Saxony afford native arsenic in some quantity. It is found also in the Harz; at Zmeov in Siberia; in the silver mines of Chile and elsewhere.

Within the boundaries of the United States arsenic occurs only in small quantity at Haverhill, N. H., at Greenwood, Me., and at a silver and gold mine near Leadville, Colo.

Uses.—Arsenic is used only in the forms of its compounds. The native metal occurs too sparingly to be of commercial importance.

Most of the arsenic compounds used in commerce are obtained from smelter fumes produced by smelting arsenical copper and gold ores.

Antimony (Sb)

Antimony is more common than arsenic, which it resembles in many respects. It is generally found in lamellar, radial and botryoidal masses, though rhombohedral crystals are known.

Most antimony contains arsenic and traces of silver, lead, iron and other metals.

Its crystals are rhombohedral or tabular in habit, and have an axial ratio of $a : c = 1 : 1.3236$. The forms observed on them are the same as those on arsenic with the addition of $\infty P2(11\bar{2}0)$, and several rhombohedrons. Twinning is often repeated. The cleavage is perfect parallel to $oP(0001)$.

Antimony exhibits brilliant cleavage surfaces with a tin-white color. On exposed surfaces the color is dark gray. The mineral differs from arsenic in its greater density which is 6.65–6.72, and in the fact that it melts (at 629°) before volatilizing. Its fumes, moreover, are devoid of the garlic odor of arsenic fumes.

Syntheses.—Crystals of antimony are often obtained from the flues of furnaces in which antimonial lead is treated. They have also been made by the reduction of antimony compounds by hydrogen at a high temperature.

Occurrence and Localities.—Antimony occurs in lamellar concretions in limestone near Sala, Sweden, and at nearly all of the arsenic localities mentioned above, especially in veins containing stibnite (Sb_2S_3) or silver ores. It is found also in fairly large quantities in veins near Fredericton, York County, New Brunswick, in California and elsewhere.

Uses.—Although the metal antimony is of considerable importance from an economic point of view, being used largely in alloys, the native mineral, on account of its rarity, enters little into commerce. Some of the antimony used in the arts is produced from its sulphide, stibnite (see p. 72). Most of the metal, however, is obtained in the form of a lead-antimony alloy in the smelting of lead ores and the refining of pig lead.

Bismuth (Bi) is usually in foliated, granular or arborescent forms, and very rarely in rhombohedral crystals, with $a : c = 1 : 1.3036$. It is silver-white with a reddish tinge, is opaque and metallic. Its streak is white, its hardness 2–2.5 and density 9.8. It fuses at 271°. On charcoal it volatilizes and gives a yellow coating. It dissolves in HNO_3. When

this solution is diluted a white precipitate results. The mineral occurs in veins with ores of silver, cobalt, lead and zinc. It is of no commercial importance. Most of the metal is obtained in the refining of lead. In 1913 the United States produced 185,000 lbs. and Bolivia about 606,000 lbs.

Tellurium (Te) usually occurs in prismatic crystals with a tin-white color and in finely granular masses in veins of gold and silver ores, especially sulphides and tellurides. Its hardness is 2 and density 6.2. Before the blowpipe it fuses, colors the flame green, coats the charcoal with a white sublimate bordered by red, and yields white fumes.

The mineral tellurium is of little value as a source of the metal. Most of that used in the arts is obtained as a by-product in the electrolytic refining of copper made from ores containing tellurides and from the flue dust of acid chambers and smelting furnaces. The United States, in 1913, produced about 10,000 lbs. of tellurium and selenium, valued at $35,000.

THE METALS

The metallic elements occur as minerals in comparatively small quantity, most of the metals used in the industries being obtained from their compounds. Iron, the most common of all the metals used in commerce, is rare as a mineral, as are also lead and tin. Silver, copper, gold and platinum are sufficiently important to be included in our list for study. Gold and platinum are known almost exclusively in the metallic state. A large portion of the copper produced in this country is also native, and some of the silver.

Silver, copper, lead, gold, mercury and the alloys of gold and mercury crystallize in distinct crystals belonging to the isometric system (hexoctohedral class). Platinum, as usually found, is in small plates and grains. Crystals, however, have been described and they, too, are isometric. Platinum and iron are separated from the other metals and, together with the rare alloys of platinum with iridium and osmium, are placed in a distinct group which is dimorphous. The reason for this is that platinum, although isometric in crystallization, often contains notable traces of iridium, which in its alloy with osmium is hexagonal (rhombohedral). Iridium, thus, is dimorphous, hence platinum which forms crystals with it and is, therefore, isomorphous with it, must also be regarded as dimorphous. The various platinum metals thus comprise an isodimorphous group. Iron is placed in the same group because it is so frequently alloyed with platinum. The metals are, therefore, divisible into two groups, one of which comprises the metals named at

the beginning of this paragraph and the other consists of the rare metals, palladium, platinum, iridium, osmium, iron and their alloys. The metal tin, which is tetragonal in its native condition, constitutes a third group, but since it is extremely rare it will not be referred to again.

GOLD GROUP

This group embraces the native metals, *copper*, *silver*, *gold*, *gold-amalgam* (Au·Hg), *silver-amalgam* (Ag·Hg), *mercury*, and *lead*. All crystallize in the isometric system (hexoctahedral class), and all form twins, with O(111) the twinning plane. Copper, silver and gold are the most important.

Copper (Cu)

Most of the copper of commerce is obtained from one or the other of its sulphides. A large portion, however, is found native. This occurs in tiny grains and flakes, in groups of crystals and in large masses of irregular shapes.

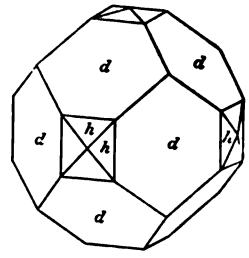


FIG. 21.—Copper Crystal with ∞O, 110 (*d*) and 2O∞, 210 (*h*).

In spite of its softness copper is better crystallized than either gold or silver. It is true that its crystals are usually flattened and otherwise distorted, but, nevertheless, planes can very frequently be detected upon them. The principal forms observed are ∞O∞ (100), ∞O(110), O(111), and various tetrahexahedra and icositetrahedra. (Figs. 21 and 22.) Sometimes the crystals are simple, in other cases they are twinned parallel to O. Often they are skeleton crystals. Groups of crystals are very common. These possess the arborescent forms so frequently seen in specimens from Keweenaw Point in Michigan, or are groupings of simple forms extended in the direction of the cubic axes.

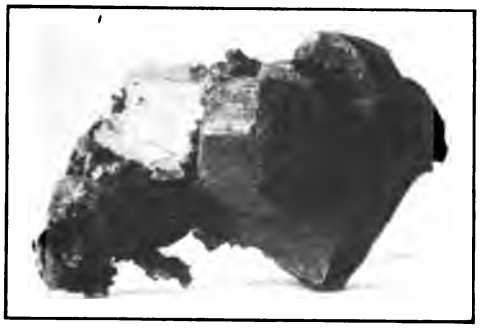


FIG. 22.—Crystal of Copper from Keweenaw Point, Mich., with ∞O(110) and 2O2(211).

Copper is very ductile and very malleable. Its hardness is only

2.5–3 and its density about 8.8. It possesses no cleavage, and its fracture, like that of the other metals, is hackly. In color it is copper-red by reflected light, often tarnishing to a darker shade of red. In very thin plates it is translucent with a green color. The metal fuses at 1083° and easily dissolves in acids. It is an excellent conductor of electricity.

Its most characteristic chemical reaction is its solubility in nitric acid with the evolution of brownish red fumes of nitrous oxide gas.

Copper may easily be distinguished from all other substances except *gold* and a few *alloys* by its malleability and color. It is distinguished from gold by the color of its borax bead and by its solubility in nitric acid with the production of a blue solution which takes on an intense azure color when treated with an excess of ammonia. From the alloys that resemble it, copper may be distinguished by its greater softness and the fact that it yields no coatings when heated on charcoal, while at the same time its solution in nitric acid yields the reaction described above.

Syntheses.—Copper crystals separate upon cooling solutions of the metal in silicate magmas and upon the electrolysis of the aqueous solutions of its salts.

Occurrence.—The principal modes of occurrence of the metal are, (1) as fine particles disseminated through sandstones and slates, (2) as solid masses filling the spaces between the pebbles and boulders making up the rock known as conglomerate, (3) in the cavities in old volcanic lavas, known as amygdaloid, (4) as crystals or groups of crystals imbedded in the calcite of veins, (5) in quartz veins cutting old igneous rocks or schists, and (6) associated with the carbonates, malachite and azurite, and with its different sulphur compounds, in the weathered zone of many veins of copper ores.

The copper that occurs in the upper portions of veins of copper sulphides is plainly of secondary origin. That which occurs in conglomerates and other fragmental rocks and in amygdaloids was evidently deposited by water, but whether by ascending magmatic water or by descending meteoric water is a matter of doubt.

Localities.—Native copper is found in Cornwall, England, in Nassau, Germany, in Bolivia, Peru, Chile and other South American countries, in the Appalachian region of the United States and in the Lake Superior region, both on the Canadian and the American sides.

The most important district in the world producing native copper is on Keweenaw Point, in Michigan. The mineral occurs mainly in a bed of conglomerate of which it constitutes from 1 to 3 per cent, though it is found abundantly also in sandstone and in the amygdaloidal cavities

of lavas associated with the conglomerates. Veins of calcite, through which groups of bright copper crystals are scattered are also very plentiful in many parts of the district. The copper is nearly always mixed with silver in visible grains and patches.

Extraction and Refining.—The rock containing the native metal is crushed and the metal is separated from the useless material by washing. The concentrates, consisting of the crushed metal mixed with particles of rock and other impurities are then refined by smelting methods or by electrolysis.

Uses.—The uses of copper are so many that all of even the important uses cannot be mentioned in this place. Both as a metal and in the form of its alloys it has been employed for utensils and war implements since the earliest times. In recent times one of its principal uses has been for the making of telegraph, telephone and trolley wires. It is employed extensively in electroplating by all the great newspapers and publishers, and is an important constituent of the valuable alloys brass, bronze, bell metal and German silver. Its compound, blue vitriol (copper sulphate), is used in galvanic batteries, and its compounds with arsenic are utilized as pigments.

Production.—The world's production of copper amounted to 1,126,000 tons in 1912, but a large portion of this was obtained from its carbonates and sulphides. The quantity obtained from the native metal is unknown. The contribution of the United States to this total was about 621,000 tons, valued at about $206,382,500, of which 115,000 tons was native copper from the Lake Superior region. The largest single mass ever found in the Lake Superior region weighed 420 tons.

Silver (Ag)

Silver is usually found in irregular masses, in flat scales, in fibrous clusters, and in crystal groups with arborescent or acicular forms. Sometimes the crystals are well developed, more frequently they exhibit only a few distinct faces, but in most cases they are so distorted that it is difficult to make out their planes.

Pure silver is unknown. The mineral as it is usually obtained contains traces of gold, copper, and often some of the rarer metals, depending upon its associations.

Ideally developed silver crystals are rare. They usually show $\infty O \infty$ (100), ∞O(110), O(111) various tetrahexahedrons and other more complicated forms. The majority of the crystals are distorted by curved faces and rounded edges, and many of them by flattening or

elongation. The arborescent groups usually branch at angles of 60°, one of the characteristic angles for groups of isometric crystals. Twins are quite common, with O(111) the twinning plane.

Silver is a white, metallic mineral when its surfaces are clean and fresh. As it usually occurs it possesses a gray, black or bluish black tarnish which is due to the action of the atmosphere or of solutions. The tarnish is commonly either the oxide or the sulphide of silver.

The mineral has no cleavage. Its fracture is hackly. It is soft (hardness 2–3), malleable and ductile, and is an excellent conductor of heat and electricity. Its density is about 10.5, varying slightly with the character and abundance of its impurities. It fuses at 960°.

It is readily soluble in nitric acid forming a solution from which a white curdy precipitate of silver chloride is thrown down on the addition of any chloride. This precipitate is easily distinguished from the corresponding lead chloride by its insolubility in hot water.

Synthesis.—Crystals bounded by O(111) and ∞O∞ (100) have been made by the reduction of silver sulphate solutions, with sulphurous acid.

Occurrence.—Native silver is found in veins with calcite ($CaCO_3$), quartz (SiO_2), and other gangues traversing crystalline rocks, like granite and various lavas, and also in veins cutting conglomerates and other rocks formed from pebbles and sands. It is also disseminated in small particles through these rocks. It occurs invisibly disseminated in small quantities through many minerals, particularly sulphides, and visibly intermingled with native copper. It is abundant in the upper weathered zones of many veins of silver-bearing ores, and in the zones of secondary enrichment in the same veins. It also occurs in small quantity in placers. In general, its origin is similar to that of gold (see p. 59).

Localities.—The localities in which silver is found are too numerous to mention. Andreasberg in the Harz has produced many fine crystallized specimens. The principal deposits now worked are at Cobalt in Canada, in Peru, in Idaho, at Butte, Montana, in Arizona and at many places in Colorado. On Keweenaw Point, in Michigan, fine crystals have been found in the calcite veins cutting the copper-bearing rocks, and masses of small size in the native copper so abundant in the district. Indeed some of the copper is so rich in silver that the ore was in early times mined almost exclusively for its silver content. At present the silver is recovered from the copper in the refining process. At Cobalt the mineral occurs in well defined veins one inch to one foot

or more in width, cutting a series of slightly inclined pre-Cambrian beds of fragmental and igneous rocks. The veins contain native silver, sulphides and arsenides of cobalt, nickel, iron and copper, calcite and a little quartz. Many of the veins are so rich (Fig. 23) that Cobalt has become one of the most important camps producing native silver in the world.

Extraction and Refining.—Silver is obtained from placers in small quantity by the methods made use of in obtaining gold (see p. 61), i.e., by hydraulic mining. When it occurs in quartz veins or in complex ores such as constitute the oxidized portion of ore-bodies, the mass may be crushed and then treated with quicksilver, which amalgamates with the native silver and gold, forming an alloy. Such ores are known

FIG. 23.—Plate of Silver from Coniagas Mine, Cobalt. Dimensions 32×14×½ ins. Weight 37 lbs. (*Photo by C. W. Knight.*)

as free milling. The silver is freed from the gold and other metals by a refining process. It is separated from native copper by electrolytic methods.

Uses.—Silver is used in the arts to a very large extent. Jewelry, ornaments, tableware and other domestic utensils, chemical apparatus and parts of many physical instruments are made of it. It is used also in the production of mirrors and in the manufacture of certain compounds used in surgery and in photography. Its alloy with copper forms the staple coinage of China, Mexico and most of the South American countries, and the subsidiary (or small) coinage of most countries. In the United States it is used in the coinage of silver dollars and of fractions of the dollar as small as the dime. The silver coins of the United States are nine-tenths silver and one-tenth copper, the latter metal being added to give hardness. English coins contain 12⅓ parts silver to one

part of copper. In 1912 the world's coinage of silver consumed 161,763,415 oz., with a value after coinage of $171,293,000.

Production.—The total production of silver in the United States during 1912 was over 63,766,000 oz., valued at over $39,197,000, of which about $100,000 worth came from placers and $325,000 worth from the copper mines of Michigan. The balance was obtained by smelting silver compounds and in the refining of gold, lead, copper and zinc ores. The world's production of silver during 1912 was 224,488,000 oz., valued at over $136,937,000, but most of this was obtained from the compounds of silver and not from the native metal. The proportion obtained from the mineral is not definitely known; but the production of Canada was more than 30,243,000 oz., valued at $17,672,000 and nearly all of this came from Cobalt, where the ore is native silver.

Gold (Au)

A large portion of the gold of the world has been obtained in the form of native metal. The greater portion of the metal is so very finely disseminated through other minerals that no sign of its presence can be detected even with high powers of the microscope. Although present in such minute quantities it is very widely spread, many rocks containing it in appreciable quantities. Its visible grains, as usually found, are little rounded particles or thin plates or scales mixed with sand or gravel, or tiny irregular masses scattered through white vein-quartz.

FIG. 24.—Octahedral Skeleton Crystal of Gold with Etched Faces.

Native gold rarely occurs in well formed crystals. The metal is so soft that its crystals are battered and distorted by very slight pressure. Occasionally well developed crystals, bounded by octahedral, dodecahedral and complicated icositetrahedral and tetrahexahedral faces are met with, but usually the crystals are elongated or flattened. Skeleton crystals (Fig. 24) and groups of crystals are more frequently found than are simple crystals. Twins are common, with O(111) the twinning plane.

As found in nature, gold is frequently alloyed with silver and it often contains traces of iron and copper and sometimes small quantities of the rarer metals.

Gold containing but a trace of silver up to 16 per cent of this metal

is known simply as gold. When the percentage of silver present is larger it is said to be argentiferous. When the percentage reaches 20 per cent or above the alloy is called *electrum*. *Palladium, rhodium* and *bismuth gold* are alloys of the last-named metal with the rare metals palladium or rhodium or with the more common bismuth.

The color of the different varieties of the mineral varies from pinkish silver-white to almost copper-red. Pure gold is golden yellow. With increase of silver it becomes lighter in color and with increase in copper, darker. The rich red-yellow of much of the gold used in the arts is due to the admixture of copper. In very thin plates or leaves (.001 mm.) gold is translucent with a blue or green tint.

Gold is soft, malleable and ductile. Its luster is, of course, metallic and its streak, yellow. When pure its density is 19.43, its hardness between 2 and 3, and its fusing point 1062°. The metal is insoluble in most acids, but it is readily dissolved in a mixture of nitric and hydrochloric acids (aqua regia). It is not acted upon by water or the atmosphere. Its negative properties distinguish it from the other substances which it resembles in appearance. It is a good conductor of electricity.

Syntheses.—Crystals of gold have been obtained by heating a solution of $AuCl_3$ in amyl alcohol, and by treating an acid solution of the same compound with formaldehyde.

Occurrence.—Native gold is found in the quartz of veins cutting through granite and schistose rocks, or in the gravels and sands of rivers whose channels cut through these, and in the sands of beaches bordering gold-producing districts. It is sometimes found in the compacted gravels of old river beds, in a rock known as conglomerate, and in sandstones. It is also present in small quantities in many volcanic rocks, and is disseminated through pyrite (FeS_2) and some other sulphur compounds and their oxidation products.

The gold in quartz veins occurs as grains and scales scattered through quartz irregularly, often in such small particles as to be invisible to the naked eye, or as aggregates of crystals in cavities in the quartz. Pyrite is nearly always associated with the gold. On surfaces exposed to the weather the pyrite rusts out and stains the quartz, leaving it cavernous or cellular.

Most of the world's supply of gold has come from placers. These are accumulations of sand or gravel in the beds of old river courses. The sands of modern streams often contain considerable quantities of gold. Many of the older streams were much larger than the modern ones draining the same regions and, consequently, their beds contain more gold. This was originally brought down from the mountains or

highlands in which the streams had their sources. The sands and gravels were rolled along the streams' bottoms and their greater portion was swept away by the currents into the lowlands. The gold, however, being much heavier than the sands and pebble grains, merely rolled along the bottoms, dropping here and there into depressions from which it could not be removed. As the streams contracted in volume the gold grains were covered by detritus, or perhaps a lava stream flowing along the old river channel buried them. These buried river channels with their stores of sands, gravels and gold constitute the placers. With the gold are often associated zircon crystals, garnets, diamonds, topazes and other gem minerals. Alluvial gold is usually in flattened scales or in aggregates of scales forming nuggets. Some of the nuggets are so large, 190 pounds or more in weight, that it is thought they may have been formed by some process of cementation after they were transported to their present positions.

The gold-quartz veins are usually closely associated with igneous rocks, but the veins themselves may cut through sedimentary beds or crystalline schists. The veins are supposed to have been filled from below by ascending solutions. Metallic gold is also present in the oxidized zones of many veins of gold-bearing sulphides and in the zones of secondary enrichment. At the surface the iron sulphides are oxidized into sulphates, leaving part of the gold in the metallic state and dissolving another part which is carried downward and precipitated.

Principal Localities.—Vein gold occurs in greater or less quantity in all districts of crystalline rocks. It has been obtained in large quantity along the eastern flanks of the Ural Mountains, this having been the most productive region in the world between the years 1819 and 1849. It has been obtained also from the Altai Mountains in Siberia, from the mountains in southeastern Brazil, from the highlands of many of the Central and South American countries, and from the western portion of the United States, more particularly from the western slopes of the Sierra Nevada Mountains and the higher portions of the Rocky Mountains. In recent years auriferous quartz veins have been worked at various points in Alaska, at Porcupine, Ontario, and other points in Canada.

The great placer mines of the world are in California, Australia and Alaska. In Australia the principal gold mines are situated in the streams rising in the mountains of New South Wales and their extension into Victoria. The valleys of the Yukon and other rivers in Alaska have lately attracted much attention, and in the past few years the beach sands off Nome have yielded much of the metal.

The most important production at present is from South Africa

where the metal occurs in an old conglomerate. In the opinion of some geologists this is an old beach deposit; in the opinion of others the gold was introduced into the conglomerate long after it had consolidated.

The sands of many streams in Europe and in the eastern United States have for many years been "panned" or washed for gold. The South Atlantic States, before the discovery of gold in California, in 1849, yielded annually about a million dollars' worth of the precious metal. All of it was obtained by working the gravels and sands of small rivers and rivulets. Many of these streams have been worked over several times at a profit and the mining continues to the present day. Small quantities of gold have also been obtained from streams in Maine, New Hampshire, Maryland and other Atlantic coast states.

Extraction and Refining.—Gold is extracted from alluvial sands and from placers by washing in pans or troughs. The sand, gravel and foreign particles are carried away by currents of water and the gold settles down with other heavy minerals to the bottom of the shallow pans used in hand washing, or into compartments prepared for it in troughs when the processes are on a larger scale. It is afterward collected by shaking it with mercury or quicksilver, in which it dissolves. The quicksilver is finally driven off by heat and the gold left behind. Auriferous beach sands and many lake, swamp and river sands are dredged and the sand thus raised is treated by similar methods. Sands containing as low as 15 cents' worth of metal per cubic yard can be worked profitably under favorable conditions.

Where the gold occurs free (not disseminated through sulphides) in quartz the rock is crushed to a fine pulp with water and the mixture allowed to flow over copper plates coated with quicksilver. The gold unites with the quicksilver and forms an alloy from which the mercury is driven off by heat. The process of forming alloys of silver or gold with mercury is known as amalgamation.

When the gold is disseminated through sulphides, these are concentrated, i.e., freed from the gangue material by washing, and then roasted. This liberates the gold which is collected by amalgamation, or is dissolved by chlorine or cyanide solutions and then precipitated.

Uses.—Gold, like silver, is used in the manufacture of jewelry and ornaments, in the manufacture of gold leaf for gilding and in the production of valuable pigments such as the "purple of Cassius." It also constitutes the principle medium for coinage in nearly all of the most important countries of the world. The gold coins of the United States contain 900 parts gold in 1,000. Those of Great Britain contain 916.66 parts, the remaining parts consisting of copper and silver. The total

gold coinage of the United States mints from the time of their organization to the end of the year 1912 amounted to $2,765,900,000. The gold coined in the world's mints in 1912 amounted in value to $360,671,382, and that consumed in arts and industries to $174,100,000. Jewelers estimate the fineness of gold in carats, 24-carat gold being pure. Eighteen-carat gold is gold containing 18 parts of pure gold and 6 parts of some less valuable metal, usually copper. The copper is added to increase the hardness of the metal and to give it a darker color. The gold used most in jewelry is 14 or 12 carats fine.

Production.—The total value of the gold product of the United States during 1912 was $93,451,000. Of this the following states and territories were the largest producers:

Alaska	$17,198,000	Nevada	$13,576,000
California	20,008,000	South Dakota	7,823,000
Colorado	18,741,000	Utah	4,312,000

Of the total product, placers yielded gold valued at $23,019,633, and quartz veins, metal valued at $62,112,000. The balance of the gold was obtained from ores mined mainly for other metals, and in these it is probably not in the metallic state. Moreover, some of the ore in quartz veins is a gold telluride, but by far the greater portion of the product from the quartz veins and placers was furnished by the native metal.

The world's yield of the precious metal in 1912 was valued at $466,136,100. The principal producing countries and the value of the gold produced by each were:

South Africa	$211,850,600	Mexico	$24,450,000
United States	93,451,500	India	11,055,700
Australasia	54,509,400	Canada	12,648,800
Russia	22,199,000	Japan	4,467,000

Lead occurs very rarely as octahedral or dodecahedral crystals, in thin plates and as small nodular masses in districts containing manganese and lead ores and also in a few placers. It usually contains small quantities of silver and antimony. The native metal has the same properties as the commercial metal. Its hardness is 1.5 and density 11.3. It melts at about 33.5°.

The mineral is of no commercial importance. The metal is obtained from galena and other lead compounds.

Mercury occurs as small liquid globules in veins of cinnabar (HgS) from which it has probably been reduced by organic substances, and in

the rocks traversed by these veins. The native metal possesses the same properties as the commercial metal. It solidifies at $-39°$, when it crystallizes in octahedrons having a cubic cleavage. Its density is 13.6. Its boiling-point is 350°.

The commercial metal is obtained from cinnabar (p. 98).

Amalgam (**Ag·Hg**) is found in dodecahedral crystals in a few places, associated with mercury and silver ores. It occurs also as embedded grains, in dense masses and as coatings on other minerals. It is silver-white and opaque and gives a distinct silver streak when rubbed on copper. Its hardness is about 3 and its density 13.9. When heated in the closed tube it yields a sublimate of mercury and a residue of silver. On charcoal the mercury volatilizes, leaving a silver globule, soluble in nitric acid.

PLATINUM-IRON GROUP

The platinum-iron group of minerals may be divided into the platinum and the iron subgroups. The latter comprises only *iron* and *nickel-iron*, both of which are extremely rare; and the former, the metals *platinum*, *iridium*, *osmium*, *ruthenium*, *rhodium*, and *palladium*. The platinum metals probably constitute an isodimorphous group since they occur together in alloys, some of which are isometric and others hexagonal (rhombohedral). Platinum is the only member of the group of economic importance.

Platinum (Pt)

Platinum occurs but rarely in crystals. It is almost universally found as granular plates associated with gold in the sands of streams and rivers, and rarely as tiny grains or flakes in certain very basic igneous rocks.

As found in nature the metal always contains iron, iridium, rhodium, palladium and often other metals. A specimen from California yielded:

Pt	Au	Fe	Ir	Rh	Pd	Cu	Ir.Os	Sand	Total
85.50	.80	6.75	1.05	1.00	.60	1.40	1.10	2.95	101.15

Though the metal occurs usually in grains and plates, nevertheless its crystals are sometimes found. On them cubic faces are the most prominent ones, though the octahedrons, the dodecahedrons and tetrahexahedrons have also been identified. Like the crystals of silver and gold, those of platinum are frequently distorted.

The color of platinum is a little more gray than that of silver. Its streak is also gray. Its hardness is 4–4.5 and density 14 to 19. Pure platinum has a density of 21.5. It is malleable and ductile, a good conductor of electricity, and it is infusible before the blowpipe except in very fine wire. It is not dissolved by any single acid, though soluble, like gold, in aqua regia. Its melting temperature is 1755°.

Syntheses.—Crystals have been obtained by cooling siliceous magmas containing the metal, and by dissolving the metal in saltpeter and cooling the mixture.

Occurrence.—Platinum is found in the sands of rivers or beaches and in placer deposits in which it occurs in flattened scales or in small grains. Nuggets of considerable size are sometimes met with, the largest known weighing about 18¾ kilos. It is present also in small quantity in certain very basic igneous rocks, like peridotite.

Localities.—It occurs in nearly all auriferous placer districts and in small quantities in the sands of many rivers, among them the Ivalo in Lapland, the Rhine, the rivers of British Columbia, and of the Pacific States. It is more abundant in the Natoos Mountains in Borneo, on the east flanks of the Ural Mountains in Siberia, in the placer of an old river in New South Wales, Australia, and the sands of rivers of the Pacific side of Colombia. It is nearly always associated with chromite (p. 200). A recent discovery which may prove to be of considerable importance is near Goodsprings, Nev., where platinum is in the free state associated with gold in a siliceous ore.

The native metal is probably an original constituent of some peridotites (basic igneous rocks). Its presence in placers is due to the disintegration of these rocks by atmospheric agencies.

Extraction and Refining.—The metal is separated from the sand with which it is mixed by washing and hand picking. The metallic powder is then refined by chemical methods.

Uses.—On account of its infusibility and its power to resist the corrosion of most chemicals the metal is used extensively for crucibles and other apparatus necessary to the work of the chemist. It is also used by dentists and by the manufacturers of incandescent electric lamps. It is an important metal in the manufacture of physical and certain surgical instruments, and was formerly used by Russia for coinage. The most important use of the metal in the industries is in the manufacture of sulphuric acid. Sulphur dioxide (SO_2) and steam when mixed and passed over the finely divided metal unite and form H_2SO_4. More than half of the acid made at present is manufactured by this process.

Production.—Most of the platinum of the world is obtained from placers in the Urals in Russia. A small quantity is washed from the sands of gold placers in Colombia, Oregon and California, and an even smaller quantity is obtained during the refining of copper from the ores of certain mines. The total production of the world in 1912 was 314,751 oz. The output for Russia in this year was about 300,000 oz., of Colombia about 12,000 oz., and of the United States 721 oz. (equivalent to 505 oz. of the refined metal, valued at $22,750). In addition, about 1,300 oz. were obtained in the refining of copper bullion imported from Sudbury, Ont., and in the treatment of concentrates from the New Rambler Mine, Wyoming. Of this about 500 oz. were produced

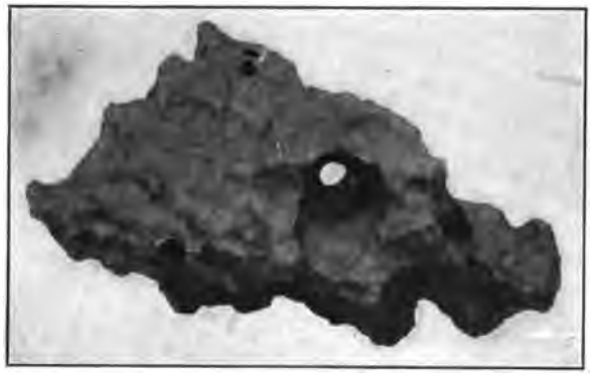


FIG. 25.—Iron Meteorite (Siderite) from Canyon Diablo, Arizona. Weight 265 lbs. (*Field Columbian Museum.*)

from domestic ores. The importations into the United States for the same year were about 125,000 oz., valued at $4,500,000.

Platinum-iron, or **iron-platinum** (**Pt·Fe**), contains from 10 per cent to 19 per cent Fe. It is usually dark gray or black and is magnetic. It is found with platinum in sands of the rivers in the Urals. Its crystals are isometric.

Iron (**Fe**) occurs in small grains and large masses in the basalt at Ovifak, Disko Island, W. Greenland, and at a few other points in Greenland, and alloys consisting mainly of iron are found in the sands of some rivers in New Zealand, Oregon and elsewhere. The native metal always contains some nickel. The most common occurrence of iron, however, is in meteorites (Fig. 25). In these bodies also it is alloyed with Ni. When

polished and treated with nitric acid, surfaces of meteoric iron exhibit series of lines (Widmanstätten figures), that are the edges of plates of different composition (Fig. 26). These are so arranged as to indicate that the substance crystallizes in the isometric system.

Iridium (**Ir·Pt**) and **platin-iridium** (**Pt·Ir**) are alloys of iridium and platinum found as silver-white grains with a yellowish tinge, associated with platinum in the sands of rivers in the Urals, Burmah and Brazil. Their hardness is 6 to 7, and density 22.7. The mineral is isometric and its fusing point is between 2150°–2250°.

FIG. 26.—Widmanstätten Figures on Etched Surface of Meteorite from Toluca, Mexico. (One-half natural size.) (*Field Columbian Museum.*)

Palladium (**Pd**) is usually alloyed with a little Pb and Ir. It is found in small octahedrons and cubes and also in radially fibrous grains in the platinum sands of Brazil, the Urals and a few other places. It is whitish steel-gray in color, has a hardness of 4 to 5 and a density of 11.3 to 11.8. It fuses at about 1549°. Its crystallization is isometric. About 2,390 oz. of the metal were produced in the United States during 1912, but all of it was obtained during the refining of bullion. The imports were 4,967 oz., valued at $213,397.

Allopalladium (**Pd**) is probably a dimorph of palladium. It is found in six-sided plates that are probably rhombohedral, intimately associated with gold, at Tilkerode, Harz.

Osmiridium (Os · Ir) and **iridosmine** (Ir · Os) are found in crystals and flattened grains and plates that are apparently rhombohedral. They consist of Ir and Os in different proportions, often with the addition of rhodium and ruthenium. Osmiridium is tin-white and iridosmine steel-gray. Their hardness is 6 to 7 and density 19 to 21. When heated with KNO_3 and KOH, both yield the distinctive chlorine-like odor of osmium oxide (OsO_4) and a green mass, which, when boiled with water, leaves a residue of blue iridium oxide. Both are insoluble in concentrated aqua regia. They occur with platinum in the sands of rivers in Colombia, Brazil, California, the Urals, Borneo, New South Wales, and a few other places. They are distinguished from platinum by greater hardness, light color and insolubility in strong aqua regia.

The world's product of refined iridium is about 5,000 oz., of which the United States furnishes about 500 oz. Its value is $63 per oz. Imports into the United States during 1911 were 3,905 oz., valued at $210,616. The sources of the metal are native iridium, osmiridium, platinum, copper ore and bullion. The metal is obtained from the last two sources in the refining process.

CHAPTER IV

THE SULPHIDES, TELLURIDES, SELENIDES, ARSENIDES AND ANTIMONIDES

THE sulphides are combinations of the metals, or of elements acting like bases, with sulphur. They may all be regarded as derivatives of hydrogen sulphide (H_2S) by the replacement of the hydrogen by some metallic element. The tellurides are the corresponding compounds of H_2Te, and the selenides of H_2Se.

With the same group are also placed the arsenides and the antimonides, derivatives of H_3As and H_3Sb, because arsenic and antimony so often replace in part the sulphur of the sulphides, forming with these isomorphous mixtures.

The minerals described in this volume may be separated into the following groups and subgroups:

I. The sulphides, tellurides and selenides of the metalloids arsenic, antimony, bismuth and molybdenum.

II. The sulphides, tellurides, selenides, arsenides and antimonides of the metals.

(*a*) The monosulphides, etc. (Derivatives of H_2S, H_2Se, H_2Te, H_3As, H_3Sb.)

(*b*) The disulphides, etc. (Derivatives of $2H_2S$, $2H_2Te$, $2H_3As$, $2H_3Sb$.)

All sulphur compounds when mixed with dry sodium carbonate (Na_2CO_3) and heated to fusion on charcoal yield a mass containing sodium sulphide (Na_2S). If the mass is removed from the charcoal, placed on a bright piece of silver and moistened with a drop or two of water or hydrochloric acid, the solution formed will stain the silver a dark brown or black color (Ag_2S), which will not rub off. The sulphides yield the sulphur reaction when heated with the carbonate on platinum foil; the sulphates only when charcoal or some other reducing agent is added to the mixture before fusing. Moreover, the sulphides yield sulphureted hydrogen when heated with hydrochloric acid, while the sulphates do not. These tests are extremely delicate. By the aid of

the first one the sulphur in any compound may be detected. By the aid of the others the sulphates may be distinguished from the sulphides.

The selenides are recognized by the strong odor evolved when heated before the blowpipe. Selenates and selenites give their odor only after reduction with Na_2CO_3.

The tellurides, when warmed with concentrated H_2SO_4, dissolve and yield a carmine solution from which water precipitates a black gray powder of tellurium.

All substances containing arsenic and antimony yield dense white fumes when heated on charcoal in the oxidizing flame. The fumes of arsenic possess a characteristic odor while those of antimony are odorless. When heated in the open tube, arsenides and compounds with sulphur and arsenic yield a very volatile sublimate composed of tiny white crystals (As_2O_3). The corresponding sublimate for antimonides and for compounds with antimony and sulphur is nonvolatile, or difficultly volatile, and apparently amorphous. It is usually found on the under side of the tube.

THE SULPHIDES, SELENIDES AND TELLURIDES OF THE METALLOIDS

The sulphides of the metalloids include compounds of sulphur with arsenic, antimony, bismuth and molybdenum and a selenide and several tellurides of bismuth. Only the sulphides are of importance. One, *stibnite* (Sb_2S_3), is utilized as a source of antimony.

Realgar (As_2S_2)

Realgar occurs as a bright red incrustation on other substances, as compact and granular masses and as crystals implanted on other minerals. It is usually associated with the bright yellow orpiment (p. 71).

Absolutely pure realgar should have the following composition: As, 70.1 per cent, S, 29.9 per cent. The mineral, however, usually contains a small amount of impurities. It may be looked upon as a derivative of H_2S in which the hydrogen of two molecules is replaced by two arsenic atoms, thus:

$$\begin{array}{ccc} H_2S & & As{=}S \\ & \text{yielding} & | \\ H_2S & & As{=}S. \end{array}$$

Crystals of realgar are usually short and prismatic in habit. They are monoclinic (prismatic class) with an axial ratio $a : b : c : = 1.44 : 1 : .973$ and $\beta = 66° \ 5'$. The characteristic prismatic faces are $(m) \infty P(110)$ and $(l) \infty P\bar{2}(210)$. These with $(b) \infty P \breve{\infty} (010)$ constitute the prismatic zone. The terminations are $(r) \frac{1}{2}P \breve{\infty} (012)$ or $(q) P \breve{\infty} (011)$ in combination with the basal plane (c) $oP(001)$, the orthodome (x) $(\bar{1}01)$, and one or more of several pyramids. (See Fig. 27.) The crystals are usually small and are striated vertically. Prismatic angle $110 \wedge 1\bar{1}0 = 105° \ 34'$.

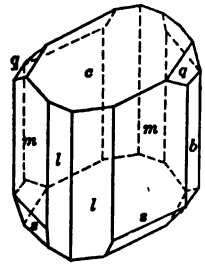


FIG. 27.—Realgar Crystal. $\infty P, 110 (m)$; $\infty P\bar{2}, 210 (l)$; $\infty P \breve{\infty}$, 010 (b); oP, 001 (c); $P \breve{\infty}$, 011 (q) and P, $\bar{1}11$ (s).

The mineral possesses a distinct cleavage parallel to $(b) \infty P \breve{\infty}$ and $(l) \infty P\bar{2}$. It is sectile, soft (H = 1.5–2), resinous in luster and aurora-red or orange in color. Its streak is a lighter shade, but with the mineral are frequently intermingled small quantities of orpiment which impart to its streak a distinct yellow tinge. Its density is 3.56. In thin splinters it is often translucent or transparent, and strongly pleochroic in red and yellow tints, but in masses it is opaque. Its indices of refraction are not known with accuracy, but its double refraction is strong (.030). It is a nonconductor of electricity.

When heated on charcoal before the blowpipe realgar catches fire and burns with a light blue flame, at the same time giving off dense clouds of arsenic fumes and the odor of burning sulphur (SO_2). When heated in a closed tube it melts, volatilizes and yields a transparent red sublimate in the cold parts of the tube.

Its bright red color and its reaction for sulphur distinguish realgar from all other minerals but *cinnabar*, the sulphide of mercury (p. 98). It may easily be distinguished from cinnabar by its softness, its low specific gravity and the arsenic fumes which it yields when heated on charcoal.

On exposure to the air and to light realgar oxidizes, yielding orpiment (As_2S_3) and arsenolite (As_2O_3).

Syntheses.—Realgar is often produced in the flues of furnaces in which ores containing sulphur and arsenic are roasted. Crystals have also been produced by heating to 150° a mixture of AsS with an excess of sulphur in a solution of bicarbonate of soda sealed in a glass tube.

Occurrence Localities and Origin.—Realgar occurs in masses associated with orpiment and in grains scattered through it at all places

where the latter mineral is found. It also occurs associated with silver and lead ores in many places. It is found in crystals implanted on quartz and on the walls of cavities in lavas. It is also occasionally a deposit from hot springs. In the United States it forms seams in a sandy clay in Iron Co., Utah. Its crystals are found in calcite in San Bernardino and Trinity Counties, California, and with orpiment it is deposited as a powder by the hot water of the Norris Geyser basin in the Yellowstone National Park.

In most cases it is a product of the interaction of arsenic and sulphur vapors.

Uses.—The native realgar occurs in too small a quantity to be of commercial importance. An artificial realgar is employed in tanning and in the manufacture of "white-fire."

Orpiment (As_2S_3)

Orpiment, though more abundant than realgar, is not a common mineral. It is usually found in foliated or columnar masses with a bright yellow color. Its name—a contraction from the Latin *auripigmentum*, meaning golden paint—refers to this color.

The pure mineral contains 39 per cent of sulphur and 61 per cent of arsenic, corresponding to the formula As_2S_3. It thus contains about 9 per cent more sulphur than does realgar.

The monoclinic orpiment crystals have the symmetry of the prismatic class. Their axial ratio is .596 : 1 : .665 with $\beta = 89° 19'$. Though always small they are distinctly prismatic with an orthorhombic habit. Their predominant faces are the ortho and clino pinacoids, several prisms and the orthodome.

The cleavage of orpiment is so perfect parallel to $\infty P \bar{\infty}$ (010) that even from large masses of the mineral distinct foliae may be split. These are flexible but not elastic. The mineral, like many other flexible minerals, is sectile. Its luster is pearly on cleavage faces, which are always vertically striated, and is resinous on other surfaces. The color of pure orpiment is lemon-yellow; it shades into orange when the mineral is impure through the admixture of realgar. Its streak is always of some lighter shade than that of the mineral. Its hardness is 1.5–2 and its density about 3.4. In small pieces orpiment is translucent and possesses an orange and greenish yellow pleochroism. When heated to 100° it becomes red and assumes the pleochroism of realgar. It, however, resumes its characteristic color and pleochroism upon cooling. When heated to 150° the change is permanent. The mineral is a nonconductor of electricity.

The chemical properties of orpiment are the same as those described for realgar, except that the sublimate in the closed tube is yellow instead of red.

Synthesis.—Orpiment is produced in large pleochroic crystals by treatment of arsenic acid with H_2S under high pressure.

Occurrence, Localities and Origin.—Orpiment occurs in the same forms and in the same places as does realgar. Small specks of it occur on arsenical iron at Edenville, N. Y. It is also found in the deposits of Steamboat Springs, Nevada. The origin of orpiment is similar to that of realgar. It is also formed by the oxidation of this mineral.

Uses.—Native orpiment mixed with water and slaked lime is used in the East as a wash for removing hair. It is also employed as a pigment in dyeing. Most of the As_2S_3 of commerce is a manufactured product.

STIBNITE GROUP (R_2Q_3)

The stibnite group of sulphides contains several isomorphous compounds, of which we shall consider only two, viz., *stibnite* (Sb_2S_3) and *bismuthinite* (Bi_2S_3). The general formula of the group is R_2Q_3, in which R stands for Sb or Bi and Q for S or Se. The group is orthorhombic (bipyramidal class). All the members have a distinct cleavage parallel to the brachypinacoid which yields flexible laminae.

Stibnite (Sb_2S_3)

Stibnite is the commonest and the most important ore of antimony. It is found in acicular and prismatic crystals, in radiating groups of crystals and in fibrous masses.

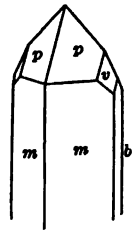


FIG. 28.—Stibnite Crystal. ∞P, 110 (*m*); ∞P$\breve{\infty}$, 010 (*b*); 2P2, 121 (*v*) and P, 111 (*p*).

Chemically, stibnite is the antimony trisulphide, Sb_2S_3, composed of Sb, 71.4 per cent and S, 28.6 per cent. As found, however, it usually contains small quantities of iron and often traces of silver and gold.

Crystals of stibnite are often very complicated. They are orthorhombic with an axial ratio .9926 : 1 : 1.0179 and a columnar or acicular habit. The most important forms in the prismatic zone are ∞P(110) and ∞P$\breve{\infty}$ (010). The prisms are often acutely terminated by P(111), $\frac{4}{3}$P$\bar{4}$(431) and 6P$\breve{2}$(361), or bluntly terminated by $\frac{1}{3}$P(113), (Fig. 28). Sometimes the crystals are rendered very complicated by the great number of their terminal

planes. Dana figures a crystal from Japan that possesses a termination of 84 planes. $110 \wedge 1\bar{1}0 = 89° 34'$.

Many of the crystals of this mineral, more particularly those with an acicular habit, are curved, bent or twisted. Nearly all, whether curved or straight, are longitudinally striated.

The cleavage of stibnite is very perfect parallel to $\infty P \breve{\infty}$ (010), leaving striated surfaces. The mineral is soft (H = 2) and slightly sectile. Its density is about 4.5. Its color is lead-gray and its streak a little darker. In very thin splinters it is translucent in red or yellow tints. In these the indices of refraction for yellow light have been determined to be, $\alpha = 4.303$ and $\gamma = 3.194$. Surfaces that are exposed to the air are often coated with a black or an iridescent tarnish. The luster of the mineral is metallic. It is a nonconductor of electricity.

Stibnite fuses very easily, thin splinters being melted even in the flame of a candle. When heated on charcoal the mineral yields antimony and sulphurous fumes, the former of which coat the charcoal white in the vicinity of the assay. When heated in the open tube SO_2 is evolved and a white sublimate of Sb_2O_3 is deposited on the cool walls of the tube. In the closed tube the mineral gives a faint ring of sulphur and a red coating of antimony oxysulphide. It is soluble in nitric acid with the precipitation of Sb_2O_5.

Stibnite may easily be distinguished from all minerals but the other sulphides by the test for sulphur. From the other sulphides it is distinguished by its cleavage and the fumes it yields when heated on charcoal. Its closest resemblance is with *galena* (PbS), which, however, differs from it in being less fusible and in yielding a lead globule when fused with sodium carbonate on charcoal. Moreover, galena possesses a cubic cleavage.

Syntheses.—Stibnite is produced by heating to 200°, a mixture of sulphur and antimony with water under pressure, and by the reaction of H_2S on antimony oxide heated to redness.

Occurrence, Localities and Origin.—The mineral is found as crystals in quartz veins cutting crystalline rocks, and in metalliferous veins associated with lead and zinc ores, with cinnabar (HgS) and barite ($BaSO_4$). The finest crystals, some of them 20 inches in length, come from mines in the Province of Iyo, on the Island of Shikoku, Japan. The mineral occurs also in York Co., New Brunswick, in Rawdon township, Nova Scotia, at many points in the eastern United States, in Sevier Co., Arkansas, in Garfield Co., Utah, and at many of the mining districts in the Rocky Mountain States.

In Arkansas stibnite is in quartz veins following the bedding planes

of shales and sandstones. With it are found many lead, zinc and iron compounds and small quantities of rarer substances. In Utah the mineral occurs in veins unmixed with other minerals, except its own oxidation products. The veins follow the bedding of sandstones and conglomerates. Here, as in Arkansas, the stibnite is believed to have been deposited by magmatic waters.

Uses.—Stibnite was powdered by the ancients and used to color the eyebrows, eyelashes and hair. At present it is used to a slight extent in vulcanizing rubber and in the manufacture of safety matches, percussion caps, certain kinds of fireworks, etc. Its principal value is as an ore of antimony. Practically all of the metal used in the arts is obtained from this source. *Antimony* is chiefly valuable as an alloy with other metals. With tin and lead it forms type metal. The principal alloys with tin are britannia metal and pewter. With lead, tin and copper it constitutes babbit metal, a hard alloy used in the construction of locomotive and car journals, and with other substances it enters into the composition of other alloys used for a variety of purposes. The double tartrate of antimony and potassium is the well known tartar emetic. The pigment, Naples yellow, is an antimony chromate.

Production.—The total quantity of stibnite mined in the world cannot be accurately estimated. That mined in the United States is very small in amount, most of the antimony produced in this country being obtained in the form of an antimony alloy as a by-product in the smelting of antimonial lead ores.

Bismuthinite (Bi_2S_3)

Bismuthinite is completely isomorphous with stibnite. It rarely, however, occurs in acicular crystals, but is more frequently in foliated, fibrous or dense masses.

Its axial ratio is .968 : 1 : .985.

The angle $110 \wedge 1\bar{1}0 = 88° 8'$.

The mineral resembles stibnite in color and streak, but its surface is often covered with a yellowish iridescent tarnish. Its fusibility and hardness are the same as those of stibnite but its density is 6.8–7.1. It is an electrical conductor.

In the open tube the mineral yields SO_2 and a white sublimate which melts into drops that are brown while hot, but change to opaque yellow when cold. On charcoal it yields a coating of yellow Bi_2O_3 which changes to a bright red BiI_3 when moistened with potassium iodide. The mineral dissolves in hot nitric acid, forming a solution, which upon the addition of water gives a white precipitate of a basic bismuth nitrate.

Bismuthinite is distinguished from *stibnite* by the coating on charcoal and by its complete solubility in HNO_3.

Syntheses.—Crystals have been obtained by cooling a solution of Bi_2S_3 in molten bismuth, and by cooling a solution made by heating Bi_2S_3 in a solution of potassium sulphide in a closed tube at 200°.

Occurrence, Localities and Origin.—Bismuthinite occurs as a constituent of veins associated with quartz, bismuth and chalcopyrite, in which it was probably formed as a product of pneumatolytic processes. It is found at Schneeberg and other points in Saxony; at Redruth and elsewhere in Cornwall; near Beaver City, Utah; in a gold-bearing vein at Gold Hill, Rowan County, N. C.; and in a vein containing beryl, garnet, etc., in granite at Haddam, Conn.

TETRADYMITE GROUP

This group comprises a series of tellurides and selenides of bismuth that have not been satisfactorily differentiated because of the lack of accurate analyses.

Tetradymite, the best known member of the group, is probably an isomorphous mixture of bismuth telluride and bismuth sulphide of the formula $Bi_2(Te \cdot S)_3$. It occurs in small rhombohedral crystals with the axial ratio 1 : 1.587 and $10\bar{1}1 \wedge \bar{1}101 = 98° 58'$. Its crystals are bounded by rhombohedrons ($R(10\bar{1}1)$ and $2R(20\bar{2}1)$) and the basal plane ($oP(0001)$). Interpenetration fourlings are common with $-\frac{1}{2}R(01\bar{1}2)$, the twinning plane. The mineral is, however, more frequently found in foliated and granular masses. Its color is lead-gray. It possesses a perfect cleavage parallel to the base. Its hardness is 1.5–2 and its density about 7.4. It is a good electrical conductor. Its best known occurrences are Zsubkau, Hungary, Whitehall, Va., in Davidson County, N. C., near Dahlonega, Ga., near Highland, Mont., and at the Montgomery Mine and at Bradshaw City in Arizona. It occurs in quartz veins associated with gold in the gold sands of some streams.

The other members of the group appear to be completely isomorphous with tetradymite. They vary in color from tin-white through gray to black.

Molybdenite (MoS_2)

This mineral, which is the sulphide of the rare metal molybdenum, does not occur in large quantity, but it is so widely distributed that it seems to be quite abundant. It occurs principally in black scales scat-

tered through coarse-grained, crystalline, siliceous rocks and granular limestones and in black or lead-gray foliated masses.

The theoretical composition of molybdenite is 40 per cent sulphur and 60 per cent molybdenum. Usually, however, the mineral contains small quantities of iron and occasionally other components.

Crystals of molybdenite are exceedingly rare. Scales and plates with hexagonal outlines are often met with but they do not usually possess sufficiently perfect faces to yield accurate measurements. The measurements that have been obtained appear to indicate a holohedral hexagonal symmetry with an axial ratio 1 : 1.908.

The cleavage of molybdenite is very perfect parallel to the base. The laminae are flexible but not elastic. The mineral is sectile and so soft that it leaves a black mark when drawn across paper. Its density is 4.7. Its luster is metallic, color lead-black, and streak greenish black. In very thin flakes the mineral is translucent with a green tinge. Otherwise it is opaque. It is a poor conductor of electricity at ordinary temperature, but its conductivity increases with the temperature.

In the blowpipe flame molybdenite is infusible. It, however, imparts to the edges of the flame a yellowish green color. Naturally, it yields all the reactions for sulphur, and in the open tube it deposits a pale yellow crystalline sublimate of MoO_3. Molybdenite is decomposed by nitric acid with the production of a gray powder (MoO_3).

By its color, luster and softness molybdenite is easily distinguished from all minerals but *graphite*. From this it is distinguished by its reaction for sulphur. Moreover, a characteristic test for all molybdenum compounds is the dark blue coating produced on porcelain when the pulverized substance is moistened with concentrated sulphuric acid and then heated until almost dry. Before this test can be applied to molybdenite, the mineral must first be powdered and then oxidized by roasting in the air for a few minutes or by boiling to dryness with a few drops of HNO_3.

Syntheses.—Crystalline molybdenite has been prepared by the action of sulphur vapor or H_2S upon glowing molybdic acid. It has also been produced by heating a mixture of molybdates and lime, in a large excess of a gaseous mixture of HCl and H_2S.

Occurrence, Localities and Origin.—Molybdenite generally occurs embedded as grains in limestone and in the crystalline silicate rocks, as, for instance, granite and gneiss, and as masses in quartz veins, at Arendal, Norway; at Blue Hill Bay, Maine; at Haddam, Conn.; in Renfrew Co., Ontario, and at many points in the far western states. It is thought to be of pneumatolytic origin.

Uses.—The mineral is the principal ore of the metal molybdenum, the salts of which are important chemicals employed principally in analytical work, especially in the detection and estimation of phosphoric acid. The molybdate of ammonia $(NH_4)_2MoO_4$, the principal salt employed in analytical processes, is easily obtained by roasting a mixture of sand and molybdenite and treating the oxidized product with ammonia. Other molybdenum salts are used for giving a green color to porcelain. The metal is used in an alloy (ferro-molybdenum) for hardening steel, as supports for the lower ends of tungsten filaments in electric lamps and for making ribbons used in electric furnaces.

Production.—There was no production of molybdenite in North America during 1912. The imports of the metal into the United States aggregated 3.5 tons, valued at $4,670. The value of the imports of the ore is not known.

THE SULPHIDES, SELENIDES, ETC., OF THE METALS

THE METALLIC MONOSULPHIDES, ETC.

The metallic monosulphides, monoselenides, etc., are compounds in which the hydrogen of H_2S, H_2Se, H_2Te, H_3As, and H_3Sb are replaced by metals. Among them are some of the most important ores.

They may be separated into several groups of which some are among the best defined of all the mineral groups, while others consist simply of a number of minerals placed together solely for convenience of description. In addition, there are a few members of this chemical group which seem to have no close relationship with any other members. These are discussed separately.

The groups described are as follows:

The Dyskrasite Group.
The Galena Group.
The Chalcocite Group.
The Blende Group.
The Millerite Group.
The Cinnabar Group.

DYSKRASITE GROUP

This group includes a number of arsenides and antimonides, some of which apparently contain an excess of the metal above that necessary to satisfy the formulas H_3As and H_3Sb. Although their com-

position is not understood, they are generally regarded as basic compounds. A few of them are well crystallized, but their composition is doubtful, because of the difficulty of obtaining pure material for analyses. Some of them are probably mixtures. The members of the group, all of which are comparatively rare, are *whitneyite* (Cu_9As), *algodonite* (Cu_6As), *domeykite* (Cu_3As), *horsfordite* (Cu_6Sb) and *dyskrasite* (Ag_3Sb). Other minerals are known which may properly be placed here, but their identity is doubtful. The only two members that need further discussion are domeykite and dyskrasite.

Domeykite (**Cu_3As**) is known only in disseminated particles and in botryoidal and dense masses and small orthorhombic crystals. It may be a mixture of several components, which in other proportions form algodonite. It is tin-white or steel-gray and opaque. It becomes dull and covered with a yellow or brown iridescent tarnish when exposed to the air. Its hardness is 3–4 and density about 7.3. It is the most easily fusible of the copper arsenides. Its principal occurrences are in the silver mines of Copiapó and Coquimbo in Chile; associated with native copper at Cerro de Paracabas, Guerrero, Mexico; at Sheldon, Portage Lake, Michigan, and on Michipicoten Island, in Lake Superior, Ontario. The last two occurrences are in quartz veins.

Dyskrasite (**Ag_3Sb**) occurs in foliated, granular and structureless masses and rarely in small orthorhombic crystals with an hexagonal habit. Their axial ratio is .5775 : 1 : .6718. Twinning is frequent, yielding star-shaped aggregates. The mineral has a silver-white color and streak, but its exposed surfaces are often tarnished yellow or black. It is opaque and sectile. Its hardness is 3.5–4 and density about 9.6. It is a good electrical conductor. Dyskrasite is soluble in HNO_3 leaving a white sediment of Sb_2O_3. It occurs principally in the silver mines of central Europe, and especially near Wolfach, Baden; St. Andreasberg, Harz; and at Carrizo, in Copiapó, Chile.

GALENA GROUP

The minerals comprising the galena group number about a dozen crystallizing in the holohedral division of the regular system (hexoctahedral class). They possess the general formula RQ in which R represents silver, lead, copper and gold, and Q sulphur, selenium and tellurium. The group may be divided into silver compounds and lead compounds, thus: (*A*) *argentite* (Ag_2S), *hessite* (Ag_2Te), *petzite* ($(Ag \cdot Au)_2Te$), *naumannite* (Ag_2Se), *aguilarite* ($Ag_2(Se \cdot S)$), *jalpaite*

($(Ag \cdot Cu)_2S$) and *eukarite* ($(Ag \cdot Cu)_2Se$), and (*B*) *galena* (PbS), *altaite* (PbTe), and *clausthalite* (PbSe). Of these only two are of importance, viz., galena, and argentite. Hessite and petzite are comparatively unimportant ores of gold.

Argentite (Ag_2S)

Argentite, though not very widespread in its occurrence, is an important ore of silver. It is found in masses, as coatings, and in crystals or arborescent groups of crystals.

Argentite contains 87.1 per cent silver and 12.9 per cent sulphur when pure. It is usually, however, impure through the admixture of small quantities of Fe, Pb, Cu, etc.

The forms most frequently observed on argentite crystals are $\infty O \infty$ (100), ∞O(110) and O(111), though various $mO\infty$ (*hlo*) and *mOm* (*hll*) forms are also met with. The crystals are often distorted and often they are grouped in parallel growths of different shapes. Twinning is common, with O(111) the twinning plane. The twins are usually penetration twins. The habit of most crystals is cubical or octahedral.

Argentite is lead-gray in color. Its streak is a little darker. The mineral is opaque. Its luster is metallic, its hardness about 2.25 and density 7.3. It is sectile, has an imperfect cleavage and is a conductor of electricity.

When heated on charcoal argentite swells and fuses, yielding sulphur fumes and a globule of silver. It is soluble in nitric acid.

Argentite is easily recognized by its color, its sectility, the fact that it yields a silver globule when fused with Na_2CO_3 on charcoal and yields the sulphur test with a silver coin.

Syntheses.—Crystals of argentite may be obtained by treating red hot silver with sulphur vapor or dry H_2S, and by heating silver and SO_2 in a closed tube at 200°.

Occurrence, Localities and Origin.—The mineral is found in the secondary enrichment zones of veins associated with silver and other sulphides in many silver-mining districts. In Nevada it is an important ore at the Comstock lode and in the Cortez district. It is found also near Port Arthur on the north shore of Lake Superior, in Ontario, and associated with native silver in the copper mines of Michigan. The ores of Mexico, Chile, Bolivia and Peru are composed largely of this mineral.

Production.—Much of the silver produced in this country is obtained from argentite, though by no means so great a quantity as is obtained from other sources.

Hessite (Ag_2Te) and Petzite ($(Ag \cdot Au)_2Te$)

These two minerals, though comparatively rare, are prominent sources of gold and silver in some mining camps. They usually occur together associated with other sulphides.

Hessite is the nearly pure silver telluride and petzite, an isomorphous mixture of gold and silver tellurides, as indicated by the following analyses of materials from the Red Cloud Mine, Boulder Co., Colorado.

	Te	Ag	Au	Cu	Pb	Fe	Zn	SiO_2	Total
I.	37.86	59.91	.22	.17	.45	1.35	...	...	99.96
II.	34.91	50.66	13.09	.07	.17	.36	.15	.70	100.01
III.	32.97	40.80	24.69	...	...	1.28	.21	.05	100.00

The minerals crystallize in all respects like argentite. They are opaque and lead-gray to iron-black in color, sectile to brittle, have a hardness between 2 and 3 and a specific gravity of 8.3–9, increasing with the percentage of gold present. They are good conductors of electricity.

Before the blowpipe, both minerals melt easily to a black globule, at the same time coloring the reducing flame greenish and giving the odor of tellurium fumes. When acted upon by the reducing flame, the globule becomes covered with little crystals of silver. With Na_2CO_3 on charcoal both minerals yield a globule of silver, but the globule obtained from hessite dissolves in warm HNO_3, while that obtained from petzite becomes yellow (gold). In the open tube both yield a white sublimate of TeO_2 which melts, when heated, to colorless drops. When heated with concentrated H_2SO_4, they give a purple or red solution which, upon the addition of water, loses its color and precipitates blackish gray, powdery tellurium. The minerals dissolve in HNO_3. From this solution HCl throws down white silver chloride.

Both the minerals resemble very closely many forms of *argentite* and *galena*, from which, however, they may be distinguished by the reactions for tellurium. Petzite and hessite may be distinguished from one another by the test for gold. Moreover a fresh surface of hessite blackens when treated with a solution of KCN, whereas a surface of petzite remains unaffected.

Syntheses.—Octahedrons of hessite are obtained by the action of tellurium vapor upon glowing silver in an atmosphere of nitrogen, and dodecahedrons of petzite upon similar treatment of gold-silver alloy.

Origin.—Both minerals are believed to be primary deposits originating in magmatic solutions. They occur in veins with native gold, quartz, fluorite, dolomite, and various sulphides and other tellurides.

Localities.—These tellurides, together with others to be described later (p. 113), are important sources of silver and gold in the mines at Nagyag, Transylvania, at Cripple Creek and in Boulder Co., Colo., and at Kalgoorlie, W. Australia. The quantity of tellurides mined is considerable, but since it is impracticable to separate these two tellurides from the other compounds of gold and silver mined with them, it is impossible to estimate the proportion of the metals obtained from them.

Galena (PbS)

Galena, the most important ore of lead, occurs in great lead-gray crystalline masses, in large and small crystals, in coarse and fine granular aggregates, and in other less common forms. Much galena contains silver, in which case it becomes an important ore of this metal.

Galena rarely approaches the theoretical composition 13.4 per cent of sulphur and 86.6 per cent of lead. It usually contains small quantities of the sulphides of silver, zinc, cadmium, copper and bismuth and in some cases native silver and gold. When the percentage of silver present reaches 3 oz. per ton the mineral is ranked as a silver ore. This silver is apparently present in some cases as an isomorphous mixture of silver sulphide and in other cases in distinct minerals included within the galena.

Galena crystals usually possess a cubical habit, though crystals with the octahedral habit are very common. The principal forms observed are $\infty O \infty$ (100), O(111), ∞O(110), $mO \infty$ (*hlo*) and *m*O*m* (*hll*) (Figs. 29 and 30). Twins are common, with O the twinning face.

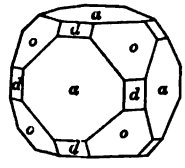


FIG. 29.—Galena Crystal. $\infty O \infty$, 100 (*a*); ∞O, 110 (*d*) and O, 111 (*o*).

Galena is well characterized by its lead-gray color, its perfect cleavage parallel to the cubic faces and by its great density (8.5). Its luster is metallic and its hardness about 2.6. Its streak is grayish black. It is a good conductor of electricity.

On charcoal galena fuses, yielding sulphurous fumes and a globule of metallic lead, which may easily be distinguished from a silver globule by its softness. The charcoal around the assay is coated with a yellow sublimate of lead oxide (PbO). The mineral is soluble in HNO_3 with the separation of sulphur.

Its color and luster distinguish galena from nearly all minerals but *stibnite*. From this mineral it is easily distinguished by its more difficult fusibility, by its cleavage, and by the fact that it does not yield the antimony fumes when heated on charcoal.

Galena weathers readily to the sulphate (anglesite) and carbonate (cerussite); consequently it is usually not found in the upper portions of veins that are exposed to the action of the air.

Syntheses.—Crystals of galena result from heating a mixture of lead oxide with NH_4Cl and sulphur, and from treatment of a lead salt with H_2S at a red heat. Small crystals have been produced by heating

FIG. 30.—Galena Crystals ($\infty O \infty$ (100) and O(111)) partly covered by Marcasite; from the Joplin District, Mo. (*After W. S. T. Smith and C. E. Siebenthal.*)

in a sealed glass tube at 80°–90° pulverized cerussite ($PbCO_3$) in a water solution of H_2S.

Origin.—Veins of galena containing silver (silver-lead) were probably produced by ascending solutions emanating from bodies of igneous rocks, while the galena in limestone was probably deposited by ground-water that dissolved the sulphide from the surrounding sedimentary rocks. Galena is also in some cases a metamorphic product.

Occurrence.—The mineral occurs very widely spread. It is found in veins associated with quartz (SiO_2), calcite ($CaCO_3$), barite ($BaSO_4$) or fluorite (CaF_2) and various sulphides, especially the zinc sulphide, sphalerite; in irregular masses filling clefts and cavities in limestone;

in beds, and in stalactites and other forms characteristic of water deposits.

It occurs also as pseudomorphs after pyromorphite—the lead phosphate. The form that occurs in veins is often silver bearing, while that in limestone is usually free from silver.

Localities.—Galena is mined in Cornwall and in Derbyshire, England; in the Moresnet district, Belgium; at various places in Silesia, Bohemia, Spain and Australia. In the United States it occurs in veins at Lubec, Me., at Rossie, St. Lawrence Co., N. Y., at Phoenixville, Penn., at Austin's Mines in Wythe Co., Va., and at many other places. It is mined for silver in Mexico; at Leadville, Colo.; at various points in Montana; in the Cœur d'Alene region in Idaho and at many other places in the Rocky Mountain region.

The most extensive galena deposits in this country are in Missouri; in the corner made by the states of Wisconsin, Illinois and Iowa; and in Cherokee Co., Kansas. In these districts the galena, associated with sphalerite (ZnS), pyrite (FeS_2), smithsonite ($ZnCO_3$), calamine ($(ZnOH)_2SiO_3$), cerussite ($PbCO_3$), calcite ($CaCO_3$) and other minerals, fills cavities in limestone.

Extraction of Lead and Silver from Galena.—The ore is first crushed and concentrated by mechanical or electrostatic methods, and the concentrates are roasted to convert them into oxides and sulphates. The mass is then heated without access of air, sulphur dioxide being driven off, leaving metallic lead carrying impurities, or a mixture of lead and silver.

The processes employed in refining the impure lead vary with the nature of the impurities.

Uses.—Galena is employed to some extent in glazing common stoneware. It is also used in the preparation of white lead and other pigments. As has already been stated, it is the most important ore of lead and a very important ore of silver.

The metal *lead* finds many uses in the arts. Its most common use is for piping. Its alloys, type metal, pewter and babbitt metal have already been referred to (p. 74). Solder is an alloy of tin and lead; Wood's metal a mixture of lead, bismuth, tin and cadmium. The special characteristic of Wood's alloy is its low fusion point (70°).

Production.—The total production of galena by the different countries of the world cannot be given, but the world's production of lead in 1912 was 1,277,002 short tons. The total quantity of lead produced by the United States from domestic ores in the same year was about 415,395 tons, valued at $37,385,550. Most of this was obtained

from galena. About 171,037 tons were soft lead, smelted from ores mined mainly for their lead and zinc contents, and the balance from ores mined partly for their silver. The importance of galena as an ore of silver may be appreciated from the fact that of the $39,197,000 worth of this metal produced in the United States during 1912, silver to the value of about $12,000,000 was obtained from lead ores or from mixtures of lead and zinc ores.

Altaite (**PbTe**) and **clausthalite** (**PbSe**) both resemble galena in appearance. Both occur commonly in fine-grained masses, but they are also found in cubic crystals. Altaite is tin-white, tarnishing to yellow or bronze, and clausthalite is lead-gray. Their hardness is 2.5–3 and specific gravity about 8.1. They are associated with silver and lead compounds principally in the silver mines of Europe and South America. Altaite is known also from several mines in California, Colorado and North Carolina. They are distinguished from one another and from *galena* by the tests for Te and Se.

CHALCOCITE GROUP

The chalcocite group includes four or five cuprous and argentous sulphides, selenides and tellurides. They all crystallize in the orthorhombic system (rhombic bipyramidal class) often with an hexagonal habit, and are isomorphous. The best known members of the group are *chalcocite* (Cu_2S) and *stromeyerite* ($(Cu \cdot Ag)_2S$, but only the first-named is common. Although these minerals are orthorhombic, nevertheless Cu_2S is known to exist also in isometric crystals, in which form it is isomorphous with argentite. Moreover, stromeyerite is an isomorphous mixture of Ag_2S and Cu_2S. Therefore, it is inferred that Cu_2S and Ag_2S are isomorphous dimorphs.

Chalcocite (Cu_2S)

Chalcocite (Cu_2S), the cuprous sulphide, is an important ore of copper though by no means as widely spread as the iron-copper sulphide, chalcopyrite. It is usually found in black masses with a dull metallic luster and as a black powder, though frequently also in crystals. It is a common constituent of the enrichment zone of many veins of copper ores.

The best analyses of chalcocite agree closely with the formula given above, requiring the presence of 20.2 per cent of sulphur and 79.8 per cent of copper. Iron and silver are often present in the mineral in small quantity.

In crystallization chalcocite is orthorhombic (rhombic bipyramidal class) with the axial ratio .5822 : 1 : .9701. Its crystals contain as their predominant forms oP(001), ∞P(110), ∞P$\breve{\infty}$(010), P(111), a series of prisms of the general symbol $\frac{1}{m}$P(11*h*), and several brachydomes. Many of the crystals are elongated parallel to *d*, and others are so developed as to possess an hexagonal habit (Fig. 31). Twins are common according to several laws. When the twinning plane is ½P (112) the twins are usually cruciform (Fig. 32). The zone 001—010 is often striated through oscillatory combinations. $110 \wedge 1\bar{1}0 = 60° 25'$.

The cleavage of chalcocite is indistinct, its fracture is conchoidal. Its hardness is 2.5–3 and density about 5.7. Its streak, like its color,

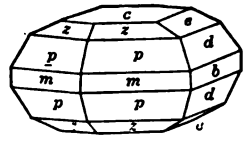


FIG. 31.

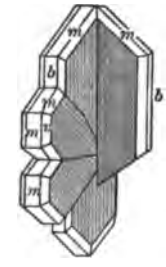


FIG. 32.

FIG. 31.—Chalcocite Crystal. oP, 001 (*c*); ∞P$\breve{\infty}$, 010 (*b*); ∞P, 110 (*m*); 2P$\breve{\infty}$, 021 (*d*); ⅔P$\breve{\infty}$, 023 (*e*); P, 111 (*p*) and ½P, 113 (*z*).

FIG. 32.—Complex Chalcocite Twin, with ∞P, 110 (*m*) and ½P, 112 (*v*) the Twinning Planes.

is nearly black, but exposed surfaces are often tarnished blue or green, probably through the production of thin films of other sulphides like covellite (CuS), chalcopyrite ($FeCuS_2$), etc. The mineral is an excellent conductor of electricity.

In the open tube or on charcoal chalcocite melts and yields sulphurous fumes.

When mixed with Na_2CO_3 and heated a copper globule is produced. The mineral dissolves in nitric acid with the production of a solution that yields the test for copper.

Upon exposure to the air chalcocite changes readily to the oxide, cuprite (Cu_2O), and the carbonates, malachite and azurite. In the presence of silicious solutions it may give rise to the silicate, chrysocolla (p. 441).

A pseudomorph of chalcocite after galena is known as *harrisite*.

It occurs at the Canton Mine in Georgia and in the Polk Co. copper mines in Tennessee. Pseudomorphs after many other copper minerals are common.

Chalcocite is recognized by its color and crystallization. Massive varieties are distinguished from *argentite* by greater brittleness and the reaction for copper; from *bornite* (Cu_3FeS_3) by the fact that it is not magnetic after roasting.

Syntheses.—Crystals of chalcocite have been made in many ways, more particularly by heating the vapors of $CuCl_2$ and H_2S, and by gently warming Cu_2O in H_2S. Measurable crystals have been observed on old bronze that has been immersed in the waters of hot springs for a long time.

Occurrence, Localities and Origin.—The mineral is a common product of the alteration of other copper compounds in the zone of secondary enrichment of sulphide veins. It is therefore present at most localities of copper minerals. One of the best known occurrences is Butte, Mont.

Fine crystals of chalcocite occur in veins and beds at Redruth and at other places in Cornwall, England; at Bristol in Connecticut, and at Joachimthal in Bohemia. The massive variety is known at many places. In the United States it occurs in red sandstone at Cheshire in Connecticut. It is found also in large quantities near Butte City in Montana, and in Washoe and other counties in Nevada, and indeed in the veins of most copper producing mines. In Canada it is present with chalcopyrite and bornite at Acton, Quebec, and at several places in Ontario north of Lake Superior.

Extraction of Copper.—Chalcocite rarely occurs alone in large quantity. In ores it is usually mixed with other compounds of copper, and is treated with them in extracting the metal (see p. 133).

Stromeyerite ($(Ag \cdot Cu)_2S$) is usually massive, but it occurs also in simple and twinned crystals similar to those of chalcocite. Their axial ratio is .5822 : 1 : .9668, almost identical with that of chalcocite. The mineral is opaque and metallic. Its color and streak are dark steel-gray. Its hardness is 2.5–3 and density about 6.2. It is soluble in nitric acid. It occurs associated with other sulphides in the ores of silver and copper mines at Schlangenberg, Altai; Kupferberg, Silesia; Coquimbo, Copiapó, and other places in Chile, and in a few mines in California, Arizona, and Colorado.

BLENDE GROUP

The blende group of minerals comprises a series of compounds whose general formula like that of the galena group is RQ. In the blendes R stands for Zn, Cd, Mn, Ni and Fe and Q for S, Se and Te.

The blendes are all transparent or translucent minerals of a lighter color than galena. They constitute an isodimorphous group of a dozen or more members crystallizing in the tetrahedral division of the regular system (hextetrahedral class), and in hemimorphic holohedral forms of the hexagonal system (dihexagonal-pyramidal class). The group may be divided into two subgroups known respectively as the sphalerite and the wurtzite groups.

SPHALERITE DIVISION

The most important member of this division of the blende group is the mineral *sphalerite*. This, like the other less well known members, crystallizes in the hemihedral division of the regular system with various tetrahedrons as prominent forms. The other members of the group are *alabandite* (MnS), and an isomorphous mixture of FeS and NiS, *pentlandite*.

Sphalerite (ZnS)

Sphalerite, one of the very important zinc ores and one of the most interesting minerals from a crystallographic standpoint, occurs in amorphous and crystalline masses and in handsome crystals and crystal groups. Botryoidal and other imitative masses are common.

Pure white sphalerite consists of 67 per cent of Zn and 23 per cent of sulphur. The colored varieties usually contain traces of silver, iron, cadmium, manganese and other metals. Sometimes the proportion of the impurities is so large that the mineral containing them is regarded as a distinct variety. Two analyses of American sphalerites are as follows:

	S	Zn	Cd	Fe	Total
Franklin Furnace, N. J.	32.22	67.46	tr	...	99.68
Joplin, Mo.	32.93	66.69	...	.42	100.04

The hemihedral condition of sphalerite is shown in the predominance of tetrahedrons among its crystal forms and by the symmetry of its etched figures (Fig. 33). Its most common forms are $-\frac{3O\frac{3}{2}}{2}(3\bar{2}1)$ and other hextetrahedrons, $\pm\frac{2O}{2}(221)$, $\frac{3O}{2}(331)$ and other deltoid-dodeca-

hedrons and $\pm 3O3(311)$ and other tristetrahedrons. In addition, $\infty O \infty$ (100) and $\infty O(110)$ are quite common (Fig. 34). Twins are abundant. Their twinning plane is O and their composition face either O (Fig. 35), or a plane perpendicular to this. Through twinning, the crystals often assume a rhombohedral habit.

The cleavage of sphalerite is perfect parallel to $\infty O(110)$. From a compact mass of the mineral a fairly good dodecahedron may sometimes be split. Its fracture is conchoidal. When pure the mineral is transparent and colorless. As usually found, however, it is yellow, translucent and black, brown, or some shade of red. Its streak is brownish, yellow or white. The yellow masses look very much like

FIG. 33.

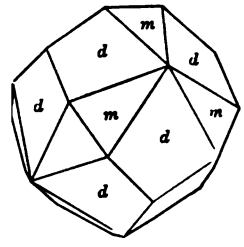


FIG. 34.

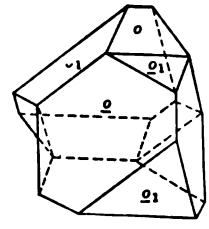


FIG. 35.

FIG. 33.—Tetrahedral Crystal of Sphalerite Bounded by $\infty O \infty$ (101) and $\pm O$ (111 and $1\bar{1}1$), Illustrating the Fact that Its Octahedral Faces Fall into Two Groups.

FIG. 34.—Sphalerite Crystal: ∞O, 110 (*d*), and $+\frac{3O3}{2}$, 311 (*m*).

FIG. 35.—Sphalerite Octahedron Twinned about O(111).

lumps of rosin. The hardness of sphalerite is between 3.5 and 4, and its density about 4. Its luster is resinous. The mineral is difficultly fusible, and is a nonconductor of electricity. Its index of refraction (*n*) for yellow light is 2.369.

Sphalerite when powdered always yields tests for sulphur under proper treatment. On charcoal it volatilizes slowly, coating the coal with a yellow sublimate when hot, turning white on cooling. When moistened with a dilute solution of cobalt nitrate and heated in the reducing flame, the white coating of ZnO turns green. The mineral dissolves in hydrochloric acid, yielding sulphuretted hydrogen.

By oxidation sphalerite changes into the sulphate of zinc, and by other processes into the silicate of zinc, calamine, or the carbonates, smithsonite and hydrozincite.

Syntheses.—Sphalerite crystals have been made by the action of H_2S upon zinc chloride vapor at a high temperature. They are also often produced in the flues of furnaces in which ores containing zinc and sulphur are roasted.

Occurrence and Origin.—Sphalerite occurs disseminated through limestone, in streaks and irregular masses in the same rock, and in veins cutting crystalline and sedimentary rocks. It is often associated with galena. The material in the veins is often crystallized. Here it is associated with chalcopyrite ($CuFeS_2$), fluorite (CaF_2), barite ($BaSO_4$), siderite ($FeCO_3$), and silver ores. When in veins it is in some cases the result of ascending hot waters and in other cases the product of downward percolating meteoric water. Much of the disseminated ore is a metamorphic contact deposit.

Localities.—Crystallized sphalerite is found abundantly at Alston Moor, Cumberland, England; at various places in Saxony; in the Binnenthal, Switzerland; at Broken Hill, N. S. Wales, and in nearly all localities for galena. Handsome, transparent, cleavable masses are brought from Pilos de Europa, Santander, Spain. Stalactites are abundant near Galena, Ill.

The principal deposits of economic importance in America are those in Iowa, Wisconsin, Missouri and Kansas, where the sphalerite is associated with other zinc compounds and with galena forming lodes in limestone, and at the silver and gold mines of Colorado, Idaho and Montana.

Extraction of the Metal.—In order to obtain the metal from sphalerite, the ore is usually first concentrated by flotation or other mechanical processes. The concentrates are then converted into the oxide by roasting and the impure oxide is mixed with fine coal and placed in clay retorts opening into a condenser. These are gradually heated. The oxide is reduced to the metal, which being volatile distils over into the condenser, where it is safely caught. Other processes are based on wet chemical methods.

Uses of Zinc.—Zinc is used extensively in galvanizing iron wire and sheets. It is also employed in the manufacture of important alloys such as brass, and in the manufacture of zinc white, which is the oxide (ZnO), and other pigments. A solution of the chloride is used for preserving timber. Argentiferous zinc is the source of a considerable quantity of silver.

Production.—The figures showing the quantity of sphalerite produced in the zinc-producing countries are not available. The total amount of metallic zinc produced in the year 1912 was 1,070,045 tons,

valued at $44,699,166, of which the United States produced from domestic ores 323,907 tons, and in addition used, in the making of zinc compounds, about 55,000 tons. Of this aggregate, Missouri produced about 149,560 tons. Most of the metal was obtained from sphalerite, but a large part came from other ores. The quantity of silver produced in refining zinc ores was 664,421 oz., valued at $408,619.

Alabandite (**MnS**) is isomorphous with sphalerite. It usually occurs, however, in dense granular aggregates of an iron-gray color. Its streak is dark green. It is opaque and brittle. Its hardness is 3–4 and density 3.9. It is not an electrical conductor. When heated on charcoal in the reducing flame it changes to the brown oxide of manganese and finally melts to a brown slag. It is soluble in dilute HCl with the evolution of H_2S. Alabandite occurs with other sulphides at Kapnik, Hungary; at Tarma, Peru; at Puebla, Mexico, and in the United States at Tombstone, Arizona, and on Snake River, Summit Co., Colorado.

Pentlandite (**(Fe·Ni)S**) may belong to this group. Iron is frequently found in crystallized sphalerite. Its sulphide, therefore, may be isomorphous with sphalerite, in which case pentlandite, which is probably an isomorphous mixture of NiS and FeS, would also belong in the sphalerite group. The mineral occurs in light bronzy yellow, granular masses with a distinct octahedral cleavage, a hardness of 3.5–5 and a density of 4.6. It is a nonconductor of electricity. Pentlandite occurs with chalcopyrite ($CuFeS_2$) and pyrrhotite (Fe_7S_8), at Sudbury, Ontario, where it is probably the constituent that furnishes most of the nickel (see p. 92).

It is distinguished from *pyrrhotite*, which it resembles in appearance, by its cleavage and the fact that it is not magnetic. Moreover, it weathers to a brassy yellow color, while pyrrhotite weathers bronze.

WURTZITE DIVISION

The wurtzite group comprises only two or three members, *wurtzite* (ZnS), *greenockite* (CdS), and possibly *pyrrhotite* (Fe_nS_{n+1}). All crystallize in the holohedral division of the hexagonal system and the first two are unquestionably hemimorphic (dihexagonal pyramidal class). Pyrrhotite is the most common.

Wurtzite (**ZnS**) is one of the dimorphs of ZnS, sphalerite being the other. It occurs in brownish black crystals, in masses and in fibers.

Its crystals are combinations of $\infty P(10\bar{1}0)$ with $2P(20\bar{2}1)$ and $oP(0001)$ at one end, and a series of steeper pyramids at the other. Their axial ratio is 1 : .8175. The angle $10\bar{1}1 \wedge 01\bar{1}1 = 40° 9'$; $2P(02\bar{2}1) \wedge 2P(02\bar{2}1) = 52° 27'$.

The mineral is brownish black to brownish yellow and its streak is brown. Its hardness is between 3 and 4 and its sp. gr. is about 4. It conducts electricity very poorly. In chemical and physical properties it resembles sphalerite. Its crystals have been produced by fusing a mixture of $ZnSO_4$, fluorite and barium sulphide. They are frequently observed as furnace products.

Wurtzite occurs as crystals at the original Butte Mine, Butte, Montana, and in a mine near Benzberg, Rhenish Prussia, at both places associated with sphalerite. They also occur with silver ores near Oruro and Chocaya, Bolivia, and near Quispisiza, Peru.

Greenockite.—Greenockite (CdS) is completely isomorphous with wurtzite. Its crystals have an axial ratio 1 : .8109. In general habit they are like those of wurtzite but they contain many more planes (Fig. 36). The angle $10\bar{1}1 \wedge 01\bar{1}1 = 39° 58'$. Crystals are rare and small. The mineral usually occurs as a coating on other minerals, especially sphalerite. Its color is honey to orange-yellow, its streak orange-yellow, and its luster glassy or resinous. It is transparent or translucent and is brittle. Its hardness is 3–3.5 and density about 4.9. Its index of refraction $\omega = 2.688$. When heated in the closed tube it becomes carmine, but it changes to its original color on cooling. It yields the usual reactions for sulphur and cadmium, and dissolves in HCl, yielding H_2S.

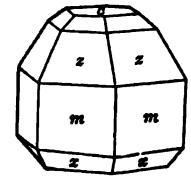


FIG. 36.—Greenockite Crystal. ∞P, $10\bar{1}0$ (m); $2P$, $20\bar{2}1$ (z); P, $10\bar{1}1$ (x), and oP, 0001 (c). (The form $\frac{1}{2}P$, $10\bar{1}2$ (i) is often present at the upper end of the crystals.)

Crystals have been obtained by melting a mixture of CdO, BaS, and CaF_2, and by heating cadmium in an atmosphere of H_2S to near fusing point. The mineral is a common furnace product. Greenockite crystals occur with prehnite at Bishoptown, Scotland, and as coatings on sphalerite in the zinc regions of Missouri and Arkansas, and at Friedensville, Pennsylvania.

Pyrrhotite (Fe_nS_{n+1})

Pyrrhotite, or magnetic pyrite, occupies the anomalous position of being one of the most important ores of nickel, whereas it is essentially a sulphide of iron. The name is really applied to a series of compounds whose composition ranges between Fe_5S_6 and $Fe_{16}S_{17}$. The crystallized material is in some cases Fe_7S_8, and in others, $Fe_{11}S_{12}$. It is probably a solid solution of FeS_2 or S in the sulphide of iron (FeS). As usually found, pyrrhotite is in bronze-gray granular masses, that tarnish rapidly to bronze on exposure to the air. Good crystals of the mineral are rare.

Analyses of pyrrhotite vary widely. The percentages of Fe and S corresponding to Fe_7S_8 are Fe, 60.4; S, 39.6, and those corresponding to $Fe_{11}S_{12}$ are Fe, 61.6; S, 38.4. Much of the mineral contains in addition to the iron and sulphur sufficient nickel to render it an ore of this metal, but it is probable that the nickel is present in pentlandite (see p. 90) or some other nickel compound embedded in the pyrrhotite.

Analyses of pyrrhotite from various localities are:

	S	Fe	Co	Ni	Total
Schneeberg, Saxony.....	39.10	61.77	tr	....	100.87
Brewster, N. Y.....	37.98	61.84	...	.25	100.07
Sudbury, Ontario.....	38.91	56.39	....	4.66	99.96
Gap Mine, Penn.....	38.59	55.82	....	5.59	100.00

The few crystals of pyrrhotite known are distinctly hexagonal in habit with $a : c = 1 : 1.7402$. They are commonly tabular or acutely pyramidal, but it has not been established that they are hemimorphic, although the almost universal presence of FeS in crystals of wurtzite would indicate that the two substances are isomorphous. The tabular crystals possess a broad basal plane, which surmounts hexagonal prisms $\infty P(10\bar{1}0)$ and $\infty P2(11\bar{2}0)$, and a series of pyramids, of which $2P(20\bar{2}1)$, $\frac{1}{2}P(10\bar{1}2)$, $P(10\bar{1}1)$ and $P2(11\bar{2}2)$ are the most frequent. (Fig. 37.) The angle $10\bar{1}1 \wedge 01\bar{1}1 = 53° 11'$.

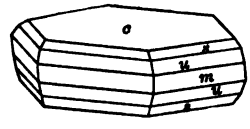


FIG. 37.—Pyrrhotite Crystal. oP, 0001 (*c*); P, $10\bar{1}1$ (*s*); 4P, $40\bar{4}1$ (*u*), and ∞P, $10\bar{1}0$ (*m*).

The cleavage of pyrrhotite is not always equally distinct. When marked it is parallel to $\infty P2(11\bar{2}0)$. There is also often a parting parallel to the base. Its fracture is uneven. The mineral is brittle. It is opaque, and has a metallic luster. Its color varies between bronze-

yellow and copper-red, and its streak is grayish black. Its hardness is a little less than 4 and its density about 4.5. All specimens are magnetic but the magnetism varies greatly in intensity, being at a maximum in the direction of the vertical axis. The mineral is a good conductor of electricity.

Pyrrhotite gives the usual reactions for iron and sulphur, and sometimes, in addition, the reactions for cobalt and nickel. It is decomposed by hydrochloric acid with the evolution of H_2S, which may easily be detected by its odor.

From the many sulphides more or less closely resembling pyrrhotite in appearance, this mineral may easily be distinguished by its color and density and by its magnetism.

Syntheses.—Crystals may be obtained by heating iron wire or Fe_3O_4, or dry $FeCl_2$ to redness in an atmosphere of dry H_2S and by heating Fe in a closed tube with a solution of $FeCl_2$ saturated with H_2S.

Occurrence, Localities and Origin.—Pyrrhotite occurs completely filling vein fissures, and also as crystals embedded in other minerals constituting veins. It occurs also as impregnations in various rocks and as a segregation in the coarse-grained basic rock known as norite, where it is believed to have separated from the magma producing the rock. It may also in some cases be a product of metamorphism on the borders of igneous intrusions.

It is found at Andreasberg, Harz; Bodenmais, Bavaria; Minas Geraes, Brazil; various points in Norway and Sweden, and on the lavas of Vesuvius. In North America crystals occur at Standish, Maine; at Trumbull, Monroe Co., N. Y.; and at Elizabethtown, Ontario. The mineral has been mined at Ducktown, Tenn.; at Ely, Vermont, and at Gap Mine, Lancaster Co., Penn.

Its mines at present, however, are at Sudbury, in Ontario, where the mineral is associated with magnetite, chalcopyrite and pentlandite ($(Fe \cdot Ni)S$) on the lower border of a great mass of igneous rock (norite). Besides these there are present also embedded in the pyrrhotite small quantities of other minerals, so that the ore as mined is very complex.

Pyrrhotite is sometimes found altered to pyrite, to limonite and to siderite ($FeCO_3$).

Extraction.—Pyrrhotite is crushed and roasted to drive off the greater portion of the sulphur. It is then placed in a furnace and smelted with coke and quartz. The nickel, copper and some of the iron, together with some of the fused sulphides, collect as a matte in the

bottom of the furnace from which it is withdrawn from time to time. The matte is next roasted to transform the iron it contains into oxides and the remaining nickel and copper are separated by patented or secret methods.

Uses.—The mineral is sometimes worked for the sulphur it contains. Its principal use, however, is as a source for nickel, nearly all of this metal used in America coming from the nickeliferous variety found at Sudbury, Ontario.

The metal nickel has come into extensive use in the past few years in connection with the manufacture of armor plate for warships. The addition of a few per cent of nickel to steel hardens it and increases its strength and elasticity.

Nickel is also extensively used in nickel-plating and in the manufacture of alloys. German silver is an alloy of nickel, copper and zinc. The nickel currency of the United States contains about 25 per cent Ni and 75 per cent Cu. Monel metal is a silver-white alloy containing about 75 per cent Ni, 1 per cent Fe and 29 per cent Cu. It is stronger than ordinary steel, takes a brilliant finish and is impervious to acids. It is made directly at Sudbury, Ont., by smelting.

Production.—The production of pyrrhotite and chalcopyrite (CuFeS) at the Sudbury mines in 1912 amounted to 737,584 short tons. The value of the matte produced was $6,303,102, and the value of nickel contained in it was about $16,000,000. About half of the nickel was used in America; the remainder, amounting to $8,515,000, was exported, after being refined in the United States. Formerly the United States produced a considerable quantity of nickel from domestic ores, most of it from pyrrhotite, but the mines have been closed down within the past few years. It is, however, produced as a by-product in the refining of copper ores to the amount of about 325 tons annually, This is worth about $260,000 (see also p. 400).

MILLERITE GROUP

This group comprises sulphides, arsenides and antimonides of nickel. It includes the minerals *millerite* (NiS), *niccolite* (NiAs), *arite* (Ni(Sb·As)) *breithauptite* (NiSb) and a few others. Of these only millerite and niccolite are at all common. The minerals all crystallize in the hexagonal system, possibly in the rhombohedral division (ditrigonal scalenohedral class). Well defined crystals are, however, rare and often capillary so that their symmetry has not been determined with certainty.

Millerite (NiS)

Millerite is easily recognized by its brass-yellow color. It occurs most frequently in slender hair-like needles, often aggregated into tufts or radial groups, or, woven together like wads of hair, forming coatings on other minerals.

Pure millerite contains 35.3 per cent sulphur and 64.6 per cent nickel. It frequently contains also a little Co and Fe.

Crystals are thin, acicular or columnar with prismatic and rhombohedral faces predominating, and an axial ratio of 1 : .330, or of 1 : .9886 if the rhombohedron $3R(03\bar{3}1)$ is taken as the ground form.

The mineral is elastic. Its hardness is 3–3.5 and density about 5.5. It is opaque and brassy yellow. Its streak is greenish black. It is an excellent conductor of electricity.

The mineral yields sulphurous fumes in the open tube. After roasting it gives, with borax and microcosmic salt, a violet bead when heated in the oxidizing flame of the blowpipe. On charcoal with Na_2CO_3 it yields a magnetic globule.

Synthesis.—Bunches of yellow acicular crystals of NiS have been formed by treatment of a solution of $NiSO_4$ with H_2S, under pressure.

Localities.—Millerite occurs as long acicular crystals in cavities in other minerals at Joachimthal, in Bohemia, and at many places in Saxony. In the United States it forms radiating groups in cavities in hematite (Fe_2O_3) at Antwerp, N. Y. At the Gap Mine, Lancaster Co., Penn., it forms coatings on other minerals and at St. Louis, Mo. and at Milwaukee, Wis., it occurs in delicate tangled tufts in geodes in limestone. Nowhere does it occur in sufficient quantity to constitute an ore.

Niccolite (NiAs)

Niccolite usually occurs massive, though crystals are known. It is of economic importance only in a few localities.

Theoretically, the mineral contains 56.10 per cent As and 43.90 per cent Ni, but as usually found it contains also Sb, S, Fe and often small quantities of Co, Cu, Pb and Bi.

Its crystals, which are rare, are hexagonal and hemimorphic (probably dihexagonal pyramidal class), with $a : c = 1 : .8194$. The prism $\infty P(10\bar{1}0)$, and $oP(0001)$ are the predominant forms, with the pyramids $P(10\bar{1}1)$ and $\frac{5}{7}P(50\bar{5}7)$ less well developed. The angle $10\bar{1}1 \wedge 01\bar{1}1 = 40° 12'$.

The mineral is pale copper-red and opaque. It has a brownish

black streak. Its hardness is about 5 and its density 7.6. The surfaces of nearly all specimens are tarnished with a grayish coating. The mineral is a good conductor of electricity.

In the open tube niccolite yields arsenic fumes and often traces of SO_2. On charcoal with Na_2CO_3 it yields a metallic globule of nickel. It dissolves in HNO_3 with the precipitation of As_2O_3. The apple-green solution, thus produced, becomes sapphire-blue on addition of ammonia.

Its peculiar light pink color and its reactions for arsenic and nickel distinguish niccolite from all other minerals, except, perhaps, *breithauptite*, which, however, contains antimony.

Occurrence.—Niccolite occurs principally in veins in crystalline schists and in metamorphosed sedimentary rocks, associated with silver and cobalt sulphides and arsenides.

Localities.—The principal locality for niccolite in North America is Cobalt, Ontario, where it is found with native silver and silver, cobalt, and other nickel compounds, all of which are thought to have been deposited by hot waters emanating from a mass of diabase. In Europe it is abundant at Joachimsthal in Bohemia, and at a number of other places in small quantity.

Although rich in nickel, the mineral is not used as an ore at present, except to a very minor extent, most of the nickel of commerce being obtained from other compounds (see p. 94).

Breithauptite (NiSb) is rare. It is of a light copper-red color, much brighter than that of niccolite, and its streak is reddish brown. Its hardness is 5.5 and density about 7.9. Its crystals are hexagonal tables with an axial ratio 1 : 1.294, and a distinct cleavage parallel to oP(001). It usually occurs in dendritic groups, in foliated and finely granular aggregates and in dense masses. It is a frequent furnace product, when ores containing Ni and Sb are smelted. It is found at Andreasberg, Harz; at Sarrabus, in Sardinia; at Cobalt, Ont., and at a few other places. It is distinguished from *niccolite* by its deeper color and its content of Sb.

Covellite (CuS)

Covellite, or indigo copper, is the cupric sulphide, chalcocite being the corresponding cuprous salt. It is called indigo copper because of the deep blue color of its fresh fracture. It is often mixed with other copper compounds from which it has been derived by alteration. It usually occurs massive, but crystals are known. It is an unimportant ore of copper.

The theoretical composition of the mineral is 33.56 per cent S, 66.44 per cent Cu. It usually, however, contains also a little iron and often traces of lead and silver.

Crystals of covellite are not common. They are hexagonal with $a : c = 1 : 3.972$ and their habit is usually tabular. The forms observed are $oP(0001)$, $\infty P(10\bar{1}0)$, $P(10\bar{1}1)$ and $\frac{1}{4}P(10\bar{1}4)$. $10\bar{1}1 \wedge 01\bar{1}1 = 77° 42'$.

The mineral has one perfect cleavage parallel to $oP(0001)$. In thin splinters it is flexible. Its hardness is 1.5–2 and density about 4.6. Its color is dark blue and its streak lead-gray to black. It is opaque, with a luster that is sometimes nearly metallic, but more frequently dull. It is a good electrical conductor.

The blowpipe reactions of covellite are like those of chalcocite, with these exceptions: Covellite burns with a blue flame when heated on charcoal, and yields a sublimate of sulphur in the closed tube.

Covellite is distinguished from other minerals than chalcocite by its reactions for Cu and S and the absence of reactions for Fe. It is distinguished from *chalcocite* by its color and density and by the fact that it ignites on charcoal.

Syntheses.—The treatment of green copper carbonate with water and H_2S in a closed tube at 80°–90° yields small grains of covellite. The mineral has also been produced by the action of H_2S upon vapor of $CuCl_2$, and by treating sphalerite with a solution of copper sulphate in a sealed glass tube containing CO_2 at a temperature of 150°–160° for two days.

Localities and Origin.—The mineral is comparatively rare. It is abundant in Chile and Bolivia and at Butte, Mont., and is found in crystals on the lava of Vesuvius and elsewhere. It usually occurs as an alteration product of other copper-sulphur compounds, especially in the zone of secondary enrichment of copper veins.

Uses.—It is mined with other compounds and used as a source of copper.

CINNABAR GROUP

This group comprises sulphides, selenides and tellurides of mercury. The group is dimorphous, with its members crystallizing in hemihedrons of the isometric system (hextetrahedral class) and in tetartohedrons of the hexagonal system (trigonal trapezohedral class). The isometric HgS is known as *metacinnabarite* and the hexagonal form as *cinnabar*. Only the latter is important. In addition to these are known the rare compounds *onofrite* (Hg(S·Se)), *tiemannite* (HgSe) and *coloradoite* (HgTe), all of which are isometric.

Cinnabar (HgS)

Cinnabar is the only compound of mercury that occurs in sufficient quantity to constitute an important ore. Nearly all of the mercury, or quicksilver, in the world is obtained from it. The mineral occurs both crystallized and massive. The ore is a red crystalline mass that is easily distinguished from all other red minerals by its peculiar shade of color and its great weight.

Theoretically, it contains 13.8 per cent S and 86.2 per cent Hg. Massive cinnabar is, however, usually impure through the admixture of clay, iron oxides or bituminous substances. Occasionally the quantity of organic material present is so large that the mixture is inflammable.

Though cinnabar is usually granular, massive or earthy, it sometimes occurs beautifully crystallized in small complex and highly modified hexagonal crystals that exhibit tetartohedral forms (trigonal trapezohedral class). Usually the crystals are rhombohedral or prismatic in habit. Their axial ratio is 1 : 1.1453. Planes belonging to more than 100 distinct forms have been observed, but the crystals on which they occur are usually so small that few of them are of importance as distinguishing characteristics. The prismatic crystals, which are the most common in this country, are often bounded by ∞ R, $(10\bar{1}0)$ and $\frac{4}{5}$R, $(40\bar{4}5)$ (Fig. 38). Others, however, are very complicated. Their cleavage is perfect parallel to ∞ R$(10\bar{1}0)$.

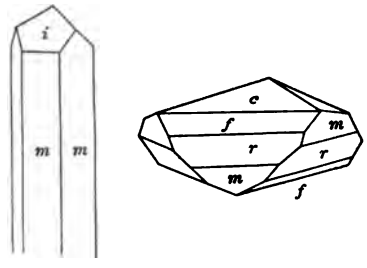


FIG. 38.—Cinnabar Crystals with ∞ R, $10\bar{1}0$ (*m*); $\frac{4}{5}$R, $40\bar{4}5$ (*i*); $\frac{2}{5}$R, $20\bar{2}5$ (*f*); R, $10\bar{1}1$ (*r*) and oR, 0001 (*c*).

The mineral is slightly sectile. It is transparent, translucent or opaque, is of a cochineal-red color, often inclining to brown, and its streak is scarlet. Its hardness is only 2–2.5 and its density about 8.1. It is circularly polarizing and is a nonconductor of electricity. Its dimorph, metacinnabarite, on the other hand, is a good conductor. The indices of refraction of cinnabar are: $\omega = 2.854$, $\epsilon = 3.201$.

When heated gently in the open tube cinnabar yields sulphurous fumes and globules of mercury. On charcoal before the blowpipe it volatilizes completely.

There are only a few minerals with which cinnabar is likely to be

confused, since its color and streak are so characteristic. From all red minerals but *realgar* it may easily be distinguished by its sulphur reaction. From realgar it is distinguished by its great density and its greater hardness.

Pseudomorphs of cinnabar after stibnite, dolomite ($(Ca \cdot Mg)CO_3$), pyrite and tetrahedrite (a complicated sulpho-salt) have been described.

Synthesis.—Crystals have been made by heating mercury in an aqueous solution of H_2S.

Occurrence, Localities and Origin.—Cinnabar is usually found in veins cutting serpentine, limestones, slates, shales and various schists. It is associated with gold, various sulphides, especially pyrite and marcasite (FeS_2), calcite ($CaCO_3$), barite ($BaSO_4$), fluorite (CaF_2) and quartz. It is also found impregnating sandstones and other sedimentary rocks, and sometimes as a deposit from hot springs. Its deposition is thought to be the result of precipitation from ascending hot water.

Crystallized cinnabar occurs at a number of places in Bohemia, Hungary, Serbia, Austria, Spain, California, Texas, Nevada, and at other localities in Europe, Asia and South America.

The principal deposits of economic importance are at Almaden in Spain, at Idria in the Province of Carniola, Austria, at Bakhmut in southern Russia, at various points along the Coast Ranges in California, in Esmeralda, Humboldt, Nye and Washoe Counties in Nevada, at many points in Oregon and Utah, and at Terlingua in Texas. The mineral is also abundant in Peru and in China but in these countries it has not yet been mined profitably. The California cinnabar district extends for many miles along the Coast Ranges, but at only about a dozen places is the mineral mined.

The Spanish mines, near the city of Cordova, have been worked for many hundreds of years. Much of the ore is an impregnation of sandstone and quartzite—the mineral sometimes comprising as much as 20 per cent of the rock mined.

Extraction.—The metallurgy of cinnabar is exceedingly simple. It consists simply in roasting the ore alone, or mixed with limestone, and conducting the fumes into a condensing chamber that is kept cool. The sulphur gases are allowed to escape through the chamber in which the mercury is collected

Uses of Metal.—Mercury finds many uses in the arts. Its most important one is in the extraction of gold and silver by the amalgamation process. It is the essential constituent of the pigment vermilion, which is a manufactured HgS. In its metallic state it is largely employed in

the making of mirrors, of barometers, thermometers and other physical instruments. Some of the salts are important medicinal preparations while others are used in the manufacture of percussion caps.

Production.—The world's annual production of quicksilver, all of which is obtained from cinnabar, is not far from 4,000 metric tons. The United States produced 940 tons in 1912, valued at $1,053,941. Of this total California yielded 20,524 flasks of 75 lbs. each, valued at about $863,034, and Texas and Nevada 4,540 flasks valued at $190,907. To produce these quantities of metal California mined 139,347 tons of ore and Texas and Nevada 16,346 tons. The California ore yielded 11 lbs. of metal per ton and the Nevada and Texas ore 20.8 lbs.

Metacinnabarite (**HgS**) is generally found as a gray-black massive mineral with a black streak. It is brittle, has a hardness of 3 and a density of 7.8. It is associated with cinnabar at some of the mines in California and Mexico, and at a few places in other countries. It is exceedingly rare.

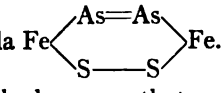
THE METALLIC DISULPHIDES, DISELENIDES AND DIARSENIDES

The disulphides, diselenides, ditellurides, diarsenides and diantimonides differ from the corresponding monocompounds in that they contain double the quantity of S, Se, Te and Sb. They are divisible into two groups, one of which comprises sulphides, arsenides and antimonides of iron, manganese, cobalt, nickel and platinum, and the other the tellurides and selenides of gold and silver.

GLANZ GROUP

The glanz group is an excellent illustration of an isodimorphous group. Its members are characterized by their hardness, opaqueness, light color and brilliant luster. Hence the name of the group. In composition the minerals belonging to the group are sulphides, arsenides or antimonides of the iron-platinum group of metals, with the general formula RQ_2 in which R is Mn, Fe, Ni, Co, Pt, and Q=S, As and Sb. The composition of the more simple members may be represented by the formula

, and of those in which arsenic or antimony replaces a part of the S by the formula



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It is probable, however, that some of the cobalt and nickel arsenides

are mixtures and that their indicated compositions are only approximate. All members of the group are believed to be dimorphous, crystallizing in the isometric (dyakisdodecahedral class), and in the orthorhombic systems (orthorhombic bipyramidal class), though not all have as yet been found in both forms. The most important members of the group, as at present constituted, are as follows:

Isometric		Orthorhombic
Pyrite	FeS_2	*Marcasite*
Hauerite	MnS_2	
	FeAsS	*Arsenopyrite*
	$FeAs_2$	*Löllingite*
Cobaltite	CoAsS	*Glaucodot*
Gersdorffite	(Ni·Fe)AsS	
Korynite	(Ni·Fe)(As·Sb·S)$_2$	*Wolfachite*
Ullmanite	NiSbS	
Smaltite	$CoAs_2$	*Safflorite*
Chloanthite	$NiAs_2$	*Rammelsbergite*
Sperrylite	$PtAs_2$	

The group is divided into two subgroups, the regularly crystallizing minerals forming the pyrite group and the orthorhombic ones the marcasite group. The most important members of the former group are *pyrite*, *cobaltite*, *smaltite* and *chloanthite*. The most important members of the marcasite group are *marcasite*, *arsenopyrite* and *löllingite*.

PYRITE DIVISION

The crystallization of the pyrite group is in the parallel hemihedral division (dyakisdodecahedral class) of the isometric system. The occurrence of the form $\left[\frac{2O\infty}{2}\right]$, 210, is so frequently seen on the mineral pyrite that it has received the name *pyritoid*.

The group is so perfectly isomorphous that a description of the forms on one member is practically a description of the forms on all.

Pyrite (FeS_2)

Pyrite, one of the most common of all minerals, is found under a great variety of conditions as crystals, as crystalline aggregates and as crystalline masses. It occurs under practically all conditions and in all situations. It is easily recognized by its bright yellow color, its brilliant luster and its hardness.

Pyrite containing, theoretically, 46.6 per cent of iron and 53.4 per cent of sulphur is usually contaminated with small quantities of nickel,

FIG. 39.—Group of Pyrite Crystals in which the Cube Predominates. The crystals are striated parallel to the edge between $\infty O \infty$ (100) and $\left(\frac{2O\infty}{2}\right)$, (210).

cobalt, thallium and other elements. An auriferous variety is worked for gold, yielding in the aggregate a large quantity of the precious

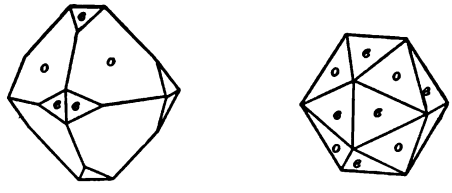


FIG. 40.

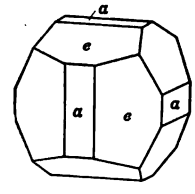


FIG. 41.

FIG. 40.—Pyrite Crystals on which O (111) Predominates. o=O, 111 and e= $\infty O2$ 210.

FIG. 41.—Pyrite Crystal with $\infty O2$, 210 (e) and O, 111 (a).

metal. Sometimes arsenic is present in small quantity. Analysis of the crystals from French Creek, Penn., gave:

S=54.08, As=0.20, Fe=44.24, Co=1.75, Ni=0.18, Cu=0.05, =100.50.

The number of forms that have been observed on pyrite crystals is very large. Hintze records 86. The cube and the pyritoid $\left[\frac{\infty O 2}{2}\right]$

FIG. 42.—Group of Pyrite Crystals in which $\infty O 2$ (210) Predominates. From Daly-Judge Mine, near Park City, Utah. (*After J. W. Boutwell.*)

(210) are the most common of these, though the octahedron and the dodecahedron are not rare. Four distinct types of crystals may be recognized, viz.: those with the cubic (Fig. 39), the octahedral (Fig. 40), and the pyritoid habits (Figs. 41 and 42), and those that are interpenetrating twins (Fig. 43). The cubic and the pyritoid planes are often striated parallel to the edges between these faces. The interpenetrating twins are twinned about the plane O(111).

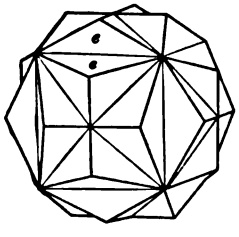


FIG. 43.—Pyrite Interpenetration Twin. Two Pyritoids ($\infty O 2$, 210) Twinned about O, 111.

The cleavage of pyrite is imperfect and its fracture conchoidal. The mineral is brittle. Its hardness is 6–6.5 and density about 5. Its luster is very brilliant and metallic. Its color is brassy yellow and its streak greenish or brownish black. With steel it strikes fire, hence its name from the Greek word meaning fire. It is a good conductor of electricity and is strongly thermo-electric.

In the closed tube pyrite yields a sublimate of sulphur and a residue that is magnetic. On charcoal sulphur is freed. This burns with the blue flame characteristic of the substance. The globule remaining after heating for some time is magnetic. Treated with nitric acid the mineral dissolves leaving a flocculent residue of sulphur, which when dried and heated may readily be ignited.

Pyrite in some of its forms so closely resembles *gold* that it is often known as fool's gold. There is, of course, no difficulty in distinguishing between the two metals, since pyrite contains sulphur and is soluble in nitric acid, while gold contains no sulphur and is insoluble in all simple acids.

The mineral is most easily confounded with *chalcopyrite* ($CuFeS_2$), though the difference in hardness of the two easily serves to distinguish them. Chalcopyrite may be readily scratched with a knife blade or a file, while pyrite resists both. The latter mineral, moreover, contains no copper.

Syntheses.—Small crystals of pyrite are produced by the action of H_2S on the oxides or the carbonate of iron enclosed in a sealed tube heated to 80°–90°; also by the passage of H_2S and $FeCl_3$ vapors through a red-hot porcelain tube.

Occurrence and Origin.—Pyrite occurs in veins and as grains or crystals embedded in all kinds of rocks. In rocks it usually appears as crystals, but in vein-masses it may appear either as crystals, with other minerals, or as radiating or structureless masses occupying entirely the vein fissures. In slates it often occurs in spheroidal nodules and concretions of various forms, and also as embedded crystals. The mineral is the product of igneous, metamorphic and aqueous agencies.

Pyrite weathers readily to limonite. In ore bodies near the surface it is oxidized. A portion of the mineral changes to $FeSO_4$ which percolates downward and aids in the concentration of any valuable metals that may be present in small quantity in the ore. Another portion of the iron remains near the surface in the form of limonite. This covering of oxidized material is known as the "gossan" and it is characteristic of all pyrite deposits.

Localities.—Pyrite crystals are so widely distributed that but very few of its most important occurrences may be mentioned here. In the mines of Cornwall, Eng., and in those on the Island of Elba very large crystals are found. Fine crystals also come from many different places in Bohemia, Hungary, Saxony, Peru, Norway, and Sweden.

In the United States the finest crystals are at Schoharie and Rossie, N. Y.; at the French Creek mines in Chester Co., and at Cornwall,

Lebanon Co., Penn., and near Greensboro and Guilford Co., N. Carolina. Massive pyrite occurs in great deposits at the Rio Tinto mines in Spain; at Rowe, Mass.; in St. Lawrence and Ulster counties, N. Y.; in Louise Co., Va., and in Paulding Co., Ga. Much of the massive pyrite in the veins of Colorado, California and of the southern states, from Virginia to Alabama, is auriferous and much of it is mined for the gold it contains.

Uses.—Pyrite is used principally in the manufacture of sulphuric acid. The mineral is burned in furnaces and the SO_2 gases thus resulting are carried to condensers where they are oxidized by finely divided platinum or by the oxides of nitrogen. The residue, which consists largely of Fe_2O_3, is sometimes smelted for iron or made into paint. This residue also contains the gold and other valuable metals that may have been in the original pyrite.

The sulphuric acid obtained from pyrite enters into many manufacturing processes. The greater portion of it is consumed in the artificial fertilizer industry.

Production.—Pyrite is mined in the United States in Franklin Co., Mass., in Alameda and Shasta Counties, California, in Louisa, Pulaski and Prince William Counties, Va., in Carroll Co., Ga., in St. Lawrence Co., N. Y., in Clay Co., Alabama, and at the coal mines in Ohio, Illinois and Indiana where it is a by-product. The total production of the United States in 1912, amounting to 350,928 long tons, was valued at $1,334,259. Virginia is by far the largest producer. In addition to this quantity the trade consumed 970,785 tons of imported ore, most of which came from Spain, and utilized the equivalent of 260,000 tons of pyrite in the shape of low grade sulphide copper ores from Ducktown, Tenn., and zinc sulphide concentrates from the Mississippi Valley and elsewhere for the manufacture of sulphuric acid. The total amount of sulphuric acid manufactured in the United States during 1912 was 2,340,000 short tons, valued at $18,338,019. The total world production of pyrite is about 2,000,000 tons annually.

Small quantities of the mineral are also mined for local consumption in Lumpkin Co., Georgia, and near Hot Springs, Arkansas. Much auriferous pyrite has also been mined in the southern states and the Rocky Mountain region for the gold it contains. This metal is separated from the pyrite partly by crushing and amalgamation and partly by smelting or by leaching processes. In the former case the gold occurs as inclusions of the metal in the pyrite.

Cobaltite (CoAsS)

Cobaltite is a silver-white or steel-gray mineral occurring in massive forms or in distinct crystals exhibiting beautifully their hemihedral character. It is completely isomorphous with the corresponding nickel compound, gersdorffite (NiAsS), and consequently mixtures of the two are common.

Cobaltite usually contains some iron and often a little nickel. Theoretically, it consists of 19.3 per cent S, 45.2 per cent As and 35.5 Co. The compositions of a massive variety from Siegen, Westphalia, and that of crystals from Nordmark, Norway, are as follows:

	As	S	Co	Fe	Ni	Total
Siegen.....	45.31	19.35	33.71	1.63		100.00
Nordmark....	44.77	20.23	29.17	4.72	1.68	100.57

The crystallization of cobaltite is perfectly isomorphous with that of pyrite, though the number of its forms observed is far smaller. The most common planes are those of $\infty O \infty$ (100), O(111) and $\left[\frac{2O\infty}{2}\right]$(210).

The cleavage of cobalt is fairly good parallel to $\infty O \infty$ (100). Its fracture is uneven, its hardness is 5.5 and its density about 6.2. The color of the mineral, as stated above, varies between silver-white and steel-gray. Its streak is grayish black. It is a good conductor of electricity.

In the open tube cobaltite reacts for S and As. On charcoal it yields a magnetic globule which when fused with borax on platinum wire yields a deep blue bead. It weathers fairly readily to the rose-colored cobalt arsenate known as *erythrite* ($Co_3(AsO_4)_2 \cdot 8H_2O$).

By its crystallization and color cobaltite is distinguished from nearly all other minerals but those of the same group. From most of these it is easily distinguished by its blowpipe reactions for sulphur, arsenic and cobalt.

Occurrence and Origin.—Cobaltite occurs mainly in veins that are believed to have been filled by upward moving solutions emanating from igneous rocks. It is associated with compounds of nickel and other cobalt compounds and with silver and copper ores.

Localities.—Cobaltite is not very widely distributed. Large, handsome crystals occur at Tunaberg in Sweden; at Nordmark, Norway; at Siegen, Westphalia, and near St. Just in Cornwall, England. It is found also in large quantity at Cobalt, Ontario, associated with silver ores and nickel compounds.

Uses.—Cobaltite is said to be used by jewelers in India in the production of a blue enamel on gold ornaments. It is employed also in the manufacture of blue and green pigments and in the manufacture of compounds used in small quantity in the various arts. Smalt is the most valuable of the cobalt pigments and is at present the chief commercial compound of this metal. It is a deep blue glass that differs from ordinary glass in containing cobalt in place of calcium. Smalt is made from cobaltite and from other cobalt ores by fusion with a mixture of quartz and potassium carbonate. Certain cobalt compounds are suggested as excellent driers for oils and varnishes. The mineral is also utilized as an ore of cobalt, which in the form of stellite, an alloy composed of 70 per cent cobalt, 15 per cent chromium and 15 per cent molybdenum or tungsten, bids fair to acquire a large use as a material for the manufacture of table cutlery and edged tools. The use of the metal has also been suggested as a material for coinage in place of nickel.

Production.—Most of the cobalt of commerce is handled by the trade in the form of the oxide. It is produced from the various cobalt minerals, mainly as a by-product in the extraction of nickel, and hence very little is obtained from cobaltite. The mines at Cobalt, however, have furnished a large quantity of cobaltite and smaltite within the past few years and these have gone into the manufacture of the oxide, of which about 515 tons were produced in 1912, having a value of $317,165.

Smaltite ($CoAs_2$)

Smaltite is another important ore of cobalt. It is found in crystals and masses.

Its theoretical composition is 71.88 per cent As and 28.12 per cent Co, though it usually contains also S, Ni, Fe and frequently traces of Bi, Cu and Pb. Since it is isomorphous with the arsenide of nickel chloanthite ($NiAs_2$), mixed crystals of the two are common. Moreover, sharply defined crystals have been found to consist of mechanical mixtures of several compounds.

Smaltite occurs in small crystals of cubical habit with $\infty O \infty$ (100), O(111) and various pyritoids predominating.

The mineral is tin-white to steel-gray, and opaque, and has a grayish black streak. It is often covered with an iridescent or a gray tarnish. Its cleavage is indistinct, its fracture uneven, its hardness 5–6 and density 6.3–7. It is a good electrical conductor.

Before the blowpipe on charcoal smaltite yields arsenic fumes and a

magnetic globule of metallic cobalt. It is soluble in HNO_3, yielding a rose-colored solution and a precipitate of As_2O_3.

The mineral is fairly easily distinguished from most other minerals by its color and blowpipe reactions. From *cobaltite* it is distinguished by the lack of S. From a few others that are not described in this volume it can be distinguished by its crystallization or by quantitative analysis.

Synthesis.—Smaltite crystals are produced when hydrogen acts at a high temperature upon a mixture of the chlorides of cobalt and arsenic.

Occurrence and Origin.—Smaltite is found associated with cobaltite in nearly all of its occurrences. It is especially abundant at Cobalt, Ont. As in the case of most other cobalt minerals, its presence is indicated by deposits of rose-colored erythrite which coat its surfaces wherever these are exposed to moist air. Its methods of occurrence, origin and uses are the same as for cobaltite (p. 107).

Chloanthite ($NiAs_2$) resembles smaltite in most of its characteristics. The two minerals grade into each other through isomorphous mixtures. Those mixtures in which the cobalt arsenide is in excess are known as smaltite, while those in which NiAs predominates are called chloanthite. The pure chloanthite molecule is Ni = 28.1 per cent, As = 71.9 per cent.

The two minerals can be distinguished when unmixed with one another by the blowpipe reactions for Co and Ni. In mixed crystals the predominance of one or the other arsenides can be determined only by quantitative analysis.

Chloanthite containing much iron is distinguished as *chathamite*, from Chatham, Conn., where it occurs with arsenopyrite and niccolite in a mica-slate.

The mode of occurrence of chloanthite and the localities at which it is found are the same as in the case of smaltite.

Sperrylite ($PtAs_2$)

Sperrylite is extremely rare. It is referred to here because it is the only platinum compound occurring as a mineral. Chemically, it is 43.53 per cent As and 56.47 per cent Pt, but it contains also small quantities of Sb, Pd and Fe.

Its crystals are simple. They contain only O(111), ∞O∞ (100), ∞O(110) and several pyritoids. Their habit is usually octahedral or cubical.

The mineral is opaque and tin-white, and its streak black. Its hardness is 6–7 and density 10.6.

In the closed glass tube it remains unchanged, but in the open tube it gives a sublimate of As_2O_3. When dropped upon red-hot platinum foil it immediately melts, giving rise to fumes of As_2O_3, and forming blisters on the foil that are not distinguishable from the original platinum in color or general character. It is slowly soluble in concentrated HCl and aqua regia.

Synthesis.—The mineral has been produced by leading arsenic fumes over red-hot platinum in an atmosphere of hydrogen.

Occurrence and Localities.—Sperrylite occurs as little crystals completely embedded in the chalcopyrite ($CuFeS_2$) and the gossan of a nickel mine, and in the chalcopyrite of a gold-quartz vein near Sudbury, Ontario; in covellite at the Rambler Mine, Encampment, Wyoming; and as flakes in the sands of streams in the Cowee Valley, Macon Co., Ga. The flakes resemble very closely native platinum, from which they are of course, easily distinguished by the test for arsenic.

Uses.—The sperrylite from Sudbury and Wyoming furnish much of the platinum produced in the United States (see p. 64).

MARCASITE DIVISION

Three members of the marcasite group are important; all are interesting from the fact that they are so alike in their crystallization that a description of the forms belonging to any one of them might serve as a description of those belonging to all others. The crystallization of the group is orthorhombic (rhombic bipyramidal class), with an axial ratio approximately $a : b : c = .7 : 1 : 1.2$.

Marcasite (FeS_2)

Marcasite, the dimorph of pyrite, resembles this mineral so closely that in massive specimens it is difficult to distinguish between the two. They are nearly alike in hardness, in color and in chemical properties. Marcasite is a little lighter in color than pyrite. Its density is less (about 4.9), and it possesses a greater tendency to tarnish on exposed surfaces.

This tarnish indicates that the mineral is more susceptible to alteration than is pyrite. One of the products of this alteration is ferrous sulphate, which may often be detected by its taste upon touching the tongue to specimens of the mineral. In crystallized specimens there is not the least difficulty in distinguishing between them, since their crystallization is very different.

Marcasite is orthorhombic (rhombic bipyramidal class), with the

axial ratio .7662 : 1 : 1.2342. Its simple crystals often possess a tabular or a pyramidal habit (Figs. 44 and 45). In the former case oP(001) is the predominant face, and in the latter case the two domes P $\bar{\infty}$ (101)

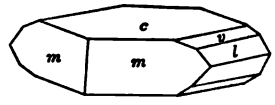


FIG. 44.

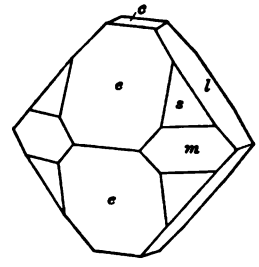


FIG. 45.

FIG. 44.—Marcasite Crystal with ∞ P, 110 (*m*); oP, 001 (*c*); P $\breve{\infty}$, 011 (*l*) and ⅓P $\breve{\infty}$, 013 (*v*).

FIG. 45.—Marcasite Crystal with Forms as Indicated in Fig. 44, and P $\bar{\infty}$, 101 (*e*) and P, 111 (*s*).

and P $\breve{\infty}$ (011). The other forms observed on most crystals are ∞ P(110), P(111), and often ⅓P $\breve{\infty}$ (013).

Twins are very common, with ∞ P(110) the twinning plane (Fig. 46). Sometimes these are aggregated by repeated twinning into serrated groups known as cockscomb twins or spearhead twins (Fig. 47), because

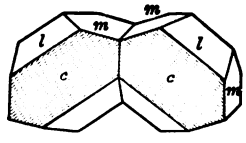


FIG. 46.

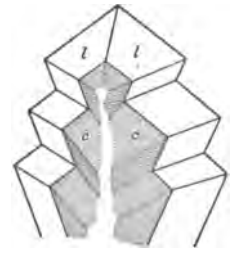


FIG. 47.

FIG. 46.—Twin of Marcasite about ∞ P(110).

FIG. 47.—Spearhead Group of Marcasite. Fourling Twinned about 110 and then about 1$\bar{1}$0.

of the outlines of their edges. In many instances the crystals are acicular or columnar in habit, forming radiating groups with globular, reniform and stalactitic shapes. Concretions are also common. The basal plane is usually striated parallel to the edge between it and P $\breve{\infty}$ (011). The cleavage is distinct parallel to ∞ P(110). The fracture is uneven

When powdered marcasite is treated with cold nitric acid and allowed to stand, it decomposes with the separation of sulphur.

Marcasite readily alters to limonite. The fact that pyrite, sphalerite, chalcopyrite, and other minerals form pseudomorphs after it indicates that, under suitable conditions, it alters also to these compounds. The mineral is in most cases a direct result of precipitation from hot solutions.

Synthesis.—Marcasite crystals have been prepared by the reduction of $FeSO_4$ by charcoal in an atmosphere of H_2S.

Occurrence and Uses.—The mineral, like pyrite, is found embedded in rocks in the form of crystals and concretions, and also as the gangue masses of veins. It constitutes nearly the entire filling of some veins, and forms druses on the walls of cavities in both rocks and minerals. It also replaces the organic matter of fossils preserving their shapes —thus producing true pseudomorphs.

When associated with pyrite it is mined together with this mineral as a source of sulphur.

Localities.—Crystalline marcasite occurs in such great quantity near Carlsbad in Bohemia that it is mined. The cockscomb variety is found in Derbyshire, England, and crystals at Schemnitz in Hungary and at Andreasberg and other places in the Harz. In the United States the mineral occurs as crystals at a great number of places, being particularly abundant in the lead and zinc localities of the Mississippi Valley, where it sometimes forms stalactites. The stalactites from Galena, Ill., often consist of concentric layers of sphalerite, galena and crystallized marcasite.

Arsenopyrite (FeAsS)

Arsenopyrite, or mispickel, is the most important ore of arsenic. It is found in crystals and in compact and granular masses. It is a silver-white metallic mineral resembling very closely cobaltite in its general appearance.

The formula FeAsS for arsenopyrite is based on analyses like the following:

	As	S	Fe	Total
Specimen from Hohenstein, Saxony....	45.62	19.76	34.64	100.02
Specimen from Mte. Chalanches, France	45.78	19.56	34.64	99.98

Theoretically, the mineral consists of its components in the following proportions, As 46 per cent, S 19.7 per cent, Fe 34.3 per cent. In many specimens the iron is replaced in part by cobalt, nickel or manganese.

Sometimes the cobalt is present in such large quantity that the mineral is smelted as an ore of this metal.

The axial ratio of arsenopyrite is .6773 : 1 : 1.1882. Its crystals are usually simpler than those of marcasite (Fig. 48), though the number of planes observed in the species is larger. Most of the untwinned crystals are a combination of $\infty P(110)$ with $\frac{1}{4}P\breve{\infty}$ (014), or $P\breve{\infty}$ (011), or $P\bar{\infty}(101)$, and have a prismatic habit. Twins are not rare. The twinning plane is the same as in marcasite, and repetition is often met with. The angle $110 \wedge 1\bar{1}0 = 68° 13'$.

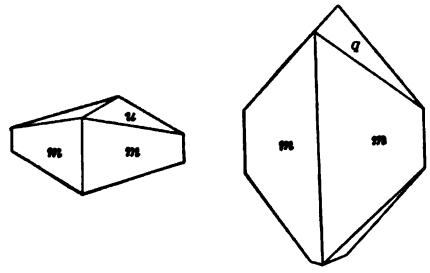


FIG. 48.—Arsenopyrite Crystals with ∞P, 110 (*m*); $\frac{1}{4}P\breve{\infty}$, 014 (*u*), and $P\breve{\infty}$, 011 (*q*).

The brachydomes are striated horizontally, and often the planes $\infty P(110)$ are striated parallel to the edge $\infty P(110) \wedge P\bar{\infty}$ (101).

The cleavage of arsenopyrite is quite perfect parallel to $\infty P(110)$. The mineral is brittle and its fracture uneven. Its hardness is 5.5–6 and density about 6.2. Its color is silver-white to steel-gray; its streak grayish black. It is a good conductor of electricity.

In the closed tube arsenopyrite at first gives a red sublimate of AsS and then a black mirror of arsenic. On charcoal it gives the usual reactions for sulphur and arsenic. Cobaltiferous varieties react for cobalt with borax. The mineral yields sparks when struck with steel and emits an arsenic smell. It dissolves in nitric acid with the separation of sulphur.

Arsenopyrite is distinguished from the cobalt sulphides and arsenides by the absence of Co.

Synthesis.—Crystals of the mineral are produced by heating in a closed tube at 300° precipitated FeAsS in a solution of $NaHCO_3$.

Occurrence.—Arsenopyrite crystals are often found disseminated through crystalline rocks, and often embedded in the gangue minerals of veins. Like pyrite and marcasite they frequently fill vein fissures. Its associates are silver, tin and lead ores, chalcopyrite, pyrite and sphalerite.

Localities.—The mineral is abundant at Freiberg, in Saxony, at Tunaberg, in Sweden, and at Inquisivi Mt., Sorato, in Bolivia.

It also occurs in fine crystals at Franconia in New Hampshire, at Blue Hill in Maine, at Chatham in Connecticut, and at St. François, Beauce Co., Quebec. Massive arsenopyrite is found near Keeseville.

Essex Co., near Edenville, Orange Co., and near Carmel, Putnam Co., N. Y., and at Rewald, Floyd Co., Va. In most cases it is apparently a result of pneumatolysis.

Uses.—Arsenopyrite was formerly the source of nearly all the arsenic of commerce. The mineral is concentrated by mechanical methods, and the concentrates are heated in retorts, when the following reaction takes place: $FeAsS = FeS + As$. The arsenic being volatile is conducted into condensing chambers where it is collected. When the mineral contains a reasonable amount of cobalt or of gold these metals are extracted.

Uses of Arsenic.—The metal arsenic has very little use in the arts, though its compounds find many applications as insecticides, medicines, pigments, in tanning, etc. The basis of most of these is As_2O_3, and this is produced directly from the fumes of smelters working on arsenical gold, silver and copper ores. Only a portion of such fumes are saved, however, as even half of those produced at a single smelter center (Butte, Montana), would more than supply the entire demand of the United States for arsenic and its compounds. Under these conditions the mining of arsenical pyrite as a source of arsenic has ceased so far as the United States is concerned.

Löllingite ($FeAs_2$) is usually massive, though its rare crystals are isomorphous in every respect with those of arsenopyrite. The pure mineral is not common. Most specimens are mixtures of löllingite with arsenopyrite or other sulphides or arsenides.

The mineral is silver-white or steel-gray. Its streak is grayish black. Its hardness is 5–5.5 and density about 7.2. It readily fuses to a magnetic globule, at the same time evolving arsenic fumes. It is soluble in HNO_3.

It usually occurs in veins associated with other sulphides and arsenides. It is found at Paris, Maine; at Edenville and Monroe, N. Y.; at various mines in North Carolina, and on Brush Creek, Gunnison Co., Colo. At the last-named locality the mineral is in star-shaped crystalline aggregates, in twins and trillings, associated with siderite and barite.

SYLVANITE GROUP

The sylvanite group includes at least three distinct minerals, all of which are ditellurides of gold or silver. The group is isodimorphous. The pure gold telluride is known only in monoclinic crystals, but the isomorphous mixtures of the gold and silver compounds occur both in monoclinic and orthorhombic crystals.

Orthorhombic bipyramidal		Monoclinic prismatic
	$AuTe_2$	*Calaverite*
Krennerite	$(Ag \cdot Au)Te_2$	*Sylvanite*

All three minerals are utilized as ores of gold. While occurring only in a few places, they are sufficiently abundant at some to be mined.

Calaverite ($AuTe_2$)

Calaverite is a nearly pure gold chloride. However, it is usually intermixed with small quantities of the silver telluride. An analysis of a specimen from Kalgoorlie, Australia, gave: Te=57.27; Au=41.37; Ag=.58.

Calaverite crystallizes in the monoclinic system (prismatic class) in crystals that are elongated parallel to the orthoaxis and deeply striated in this direction. Their axial ratio is 1.6313 : 1 : 1.1449 with $\beta = 90° 13'$.

The prominent forms are $\infty P \bar{\infty}$ (100), $\infty P \bar{\infty}$ (010), oP(001), $-P \bar{\infty}$ (101), $+P \bar{\infty}$ ($10\bar{1}$), $-2P \bar{\infty}$ (201), $+2P \bar{\infty}$ ($20\bar{1}$), and P(111). Twinning is common and the resulting twins are very complicated. Usually, however, the mineral occurs massive and granular.

Calaverite is opaque, silver-white or bronzy yellow in color and has a yellow-gray or greenish gray streak. Its surface is frequently covered with a yellow tarnish. The mineral is brittle and without distinct cleavage. Its hardness is 2–3 and density 9.04.

On charcoal before the blowpipe the mineral fuses easily to a yellow globule of gold, yielding at the same time the fumes of tellurium oxide. It dissolves in concentrated H_2SO_4, producing a deep red solution. When treated with HNO_3 it decomposes, leaving a rusty mass of spongy gold. The solution treated with HCl usually yields a slight precipitate of silver chloride.

Calaverite is distinguished from most other minerals by the test for tellurium. It is distinguished from *petzite* (p. 80), by its crystallization and the fact that it gives a yellow globule when roasted on charcoal, and from *sylvanite* by the small amount of silver it contains, its higher specific gravity, its color and its lack of cleavage. It is distinguished from *krennerite* by its crystallization.

Occurrence.—The mineral occurs in veins with the other tellurides associated with gold ores in Calaveras Co., Cal., and at the localities mentioned for petzite (see p. 81). It is believed to have been deposited by pneumatolytic processes or by ascending magmatic water at comparatively low temperatures.

Uses.—The mineral is mined with other tellurides in Boulder Co., and at Cripple Creek, Colorado, as an ore of gold.

Sylvanite $(Ag \cdot Au)Te_2$

Sylvanite is more common than calaverite. It is an isomorphous mixture of gold and silver tellurides in the ratio of about 1 : 1. Analyses follow:

I.	Te=62.16	Au=24.45	Ag=13.39	Total=100.00
II.	Te=59.78	Au=26.36	Ag=13.86	" 100.00
III.	Te=58.91	Au=29.35	Ag=11.74	" 100.00

I. Theoretical for $AgTe_2+AuTe_2$.
II. and III. Specimens from Boulder Co., Colo.

In crystallization the mineral is isomorphous with calaverite, with an axial ratio $a : b : c = 1.6339 : 1 : 1.1265$ and $\beta = 90° 25'$. Its crystals are usually rich in planes, about 75 having been identified. Their habit is usually tabular parallel to $\infty P \breve{\infty}$ (010), with this plane, $-P \bar{\infty}$ (101), oP(001), $\infty P \bar{\infty}$ (100) and $2P\breve{2}(\bar{1}21)$ predominating. The mineral also occurs in skeleton crystals and in aggregates that are platy or granular. Twinning is common, with $-P \bar{\infty}$ (101) the twinning plane. Many twinned aggregates form networks suggesting writing, hence the name "Schrifterz" often applied to the mineral by the Germans.

Sylvanite is silver-white or steel-gray and has a brilliant metallic luster and a silver-white or yellowish gray streak. Its hardness is between 1 and 2 and its density 7.9–8.3. Moreover, it possesses a perfect cleavage parallel to $\infty P \breve{\infty}$ (010).

Its chemical properties are the same as those of calaverite, but the silver precipitate produced by adding HCl to its solution in HNO_3 is always large. It is best distinguished from the gold telluride by its cleavage and from *petzite* ($(Ag.Au)_2Te$) and *hessite* (Ag_2Te) by its crystallization, and by the yellow metallic globule produced when the mineral is roasted on charcoal. It is distinguishable from *krennerite* by its crystallization.

Localities and Origin.—Sylvanite occurs with the other tellurides in veins at Offenbánya and Nagyag in Transylvania, at Cripple Creek and in Boulder Co., Colo., near Kalgoorlie, W. Australia, in small quantities near Balmoral in the Black Hills, S. D., and at Moss, near Thunder Bay, Ontario. Like calaverite it was deposited by magmatic water, or by hot vapors.

Uses.—It is mined with calaverite as a gold and silver ore at Cripple Creek and in Boulder Co., Colo.

CHAPTER V

THE SULPHO-SALTS AND SULPHO-FERRITES

THE sulpho-salts are salts of acids analogous to arsenic acid, H_3AsO_4, and arsenious acid, H_3AsO_3, and the corresponding antimony acids H_3SbO_4 and H_3SbO_3. The sulpho-acids differ from the arsenic and the antimony acids in containing sulphur in place of oxygen, thus H_3AsS_4, H_3AsS_3, H_3SbS_4 and H_3SbS_3. The mineral enargite may be regarded as a salt of sulpharsenic acid, thus Cu_3AsS_4, copper having replaced the hydrogen of the acid. Proustite, on the other hand, is Ag_3AsS_3, or a salt of sulpharsenious acid. The salts of sulpharsenic acid are called sulpharsenates, while those derived from sulpharsenious acid are known as sulpharsenites. The sulpharsenates are not represented among the commoner minerals, although the copper salt enargite is abundant at a few places. A number of salts of other sulphur-arsenic acids are known but they are comparatively rare.

There is another class of compounds with compositions analogous to those of the sulpho-salts, though their chemical nature is not well understood. This is the group of the sulpho-ferrites. We know that certain hydroxides of iron may act as acids under certain conditions. The sulpho-ferrites may be looked upon as salts of these acids in which, however, the oxygen has been replaced by sulphur, as in the case of the sulpho-acids referred to above. Thus by replacement of O by S, in ferric hydroxide $Fe(OH)_3$ the compound $Fe(SH)_3$ or H_3FeS_3 results. The salts of this acid are sulpho-ferrites. This acid, by loss of H_2S, may give rise to other acids in the same way that sulphuric acid (H_2SO_4), by loss of H_2O, gives rise to pyrosulphuric acid. In the case of the sulpho-acid we may have $H_3FeS_3 - H_2S = HFeS_2$. The copper salt of this acid is the common mineral chalcopyrite, $CuFeS_2$.

The sulpho-salts are very numerous, but only a few of them are of sufficient importance to warrant a description in this book.

THE SULPHARSENITES AND SULPHANTIMONITES

The sulpharsenites and sulphantimonites are derivatives of the ortho acids H_3AsS_3 and H_3SbS_3.

ORTHO SULPHO-SALTS

The ortho salts are compounds in which the hydrogen of the ortho acids is replaced by metals. They include a large number of minerals, of which the following are the most important.

Bournonite	$(Cu_2 \cdot Pb)_3 (SbS_3)_2$	Orthorhombic
Pyrargyrite	Ag_3SbS_3	Hexagonal
Proustite	Ag_3AsS_3	Hexagonal

PYRARGYRITE GROUP

Pyrargyrite (Ag_3SbS_3)

Pyrargyrite, or dark ruby silver, is an important silver ore, especially in Mexico, Chile and the western United States. The name ruby silver is given to it because thin splinters transmit deep red light. The mineral is usually mixed with other ores in compact masses, but it also forms handsome crystals.

The composition of pyrargyrite is represented by the formula Ag_3SbS_3 which demands 17.82 per cent S.; 22.21 per cent Sb.; 59.97 per cent Ag. Many specimens contain also a small quantity of arsenic, through the admixture of the isomorphous compound proustite. The analyses given below show the effect of the intermixture of the two molecules.

	S	Sb	As	Ag	Total
Andreasberg, Harz....	17.65	22.36	....	59.73	99.77
Zacatecas, Mexico.....	17.74	22.39	.27	60.04	100.44
Freiberg, Saxony.....	17.95	18.58	2.62	60.63	99.78

The crystals of pyrargyrite are rhombohedral and hemimorphic (ditrigonal pyramidal class), with an axial ratio 1 : .8038. They are usually quite complex and are often twinned. The species is very rich in forms, not less than 150 having been reported. The most prominent of these are $\infty P2(11\bar{2}0)$, $\infty P(10\bar{1}0)$, $R(10\bar{1}1)$, $-\frac{1}{2}R(01\bar{1}2)$ and the scalenohedrons $R^3(21\bar{3}1)$ and $\frac{1}{4}R^3(21\bar{3}4)$ (Fig. 49). In the commonest twinning law the twinning plane is $\infty P2(11\bar{2}0)$ and the composition

face oP(001). The *c* axes in the twinned portions are parallel and the $\infty P2(11\bar{2}0)$ planes coincident, so that the twin at a hasty glance looks like a simple crystal. The angle $10\bar{1}1 \wedge \bar{1}101 = 71° 22'$.

The cleavage of pyrargyrite is distinct parallel to $R(10\bar{1}1)$. Its fracture is conchoidal or uneven. The mineral is apparently opaque and its color is grayish black in reflected light, but is transparent or translucent and deep red in transmitted light. Its streak is purplish red. For lithium light $\omega = 3.084$, $\epsilon = 2.881$. It is not an electrical conductor.

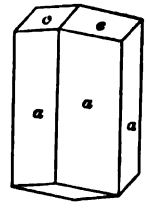


FIG. 49.—Crystal of Pyrargyrite with $\infty P2$, $11\bar{2}0$ (*a*) and $-\frac{1}{2}R, 01\bar{1}2$ (*e*).

In the closed tube the mineral fuses easily and gives a reddish sublimate. When heated with sodium carbonate on charcoal it is reduced to a globule of silver, which, when dissolved in nitric acid, yields a silver chloride precipitate when treated with a soluble chloride. The mineral dissolves in nitric acid with the separation of sulphur and a white precipitate of antimony oxide. It is also soluble in a strong solution of KOH. From this solution HCl precipitates orange Sb_2S_3 (compare proustite).

The color and streak of pyrargyrite, together with its translucency, distinguish it from nearly all other minerals. Its reaction for silver serves to distinguish it from *cuprite*, *cinnabar* and *realgar*, which it sometimes resembles. The distinction between this mineral and its isomorph, *proustite*, is based on the streak and the reaction for antimony.

Pyrargyrite occurs as a pseudomorph after native silver. On the other hand it is occasionally altered to pyrite or argentite, and sometimes to silver.

Syntheses.—Microscopic crystals have been made by heating in a porcelain tube, metallic silver and antimony chlorides in a current of H_2S, and by the action of the same gas at a red heat on a mixture of metallic silver and melted antimony oxide.

Occurrence, Localities and Origin.—Pyrargyrite occurs in veins associated with other compounds of silver and sometimes with galena and arsenic. It is most common in the zone of secondary enrichment of silver veins. The crystallized variety is found at Andreasberg in the Harz; at Freiberg, in Saxony; at Přibram, in Bohemia; at many places in Hungary, and at Chañarcillo, in Chile. The massive variety is worked as an ore of silver at Guanajuato in Mexico and in several of the western states, as, for instance, in the Ruby district, Gunnison Co., and in other

mining districts in Colorado, near Washoe and Austin, Nevada, and at several points in Idaho, New Mexico, Utah and Arizona.

Uses.—The mineral is an important ore of silver in Mexico and in the western United States. It is usually associated with other sulphur-bearing ores of silver, the metal being extracted from the mixture by the processes referred to under argentite.

Proustite (Ag_3AsS_3)

Proustite, or light ruby silver, is isomorphous with pyrargyrite. It differs from the latter mineral in containing arsenic in place of antimony. It occurs both massive and in crystals, and like pyrargyrite is an ore of silver.

The formula above given demands 19.43 per cent S; 15.17 per cent As; and 65.40 per cent silver. The analysis of a specimen from Mexico yields figures that correspond very nearly to these. Crystals from Chañarcillo contain a slight admixture of the antimony compound.

	S	As	Sb	Ag	Total
Mexico.....	19.52	14.98	....	65.39	99.89
Chañarcillo, Chile.....	19.64	13.85	1.41	65.06	99.96

Like pyrargyrite, proustite is rhombohedral. Its crystals are prismatic or acute rhombohedral. The forms present on them are much less numerous than those on the corresponding antimony compound, the predominant ones being $\infty P2(11\bar{2}0)$, $\frac{1}{4}R(10\bar{1}4)$, $-\frac{1}{2}R(01\bar{1}2)$, $R^3(21\bar{3}1)$, $-\frac{2}{7}R^4(35\bar{8}7)$ and other scalenohedrons (see Fig. 50). Twins are common, the twinning planes being (1), parallel to $\frac{1}{4}R(10\bar{1}4)$ and (2) parallel to $R(10\bar{1}1)$. The angle $10\bar{1}1 \wedge \bar{1}101 = 72° 12'$.

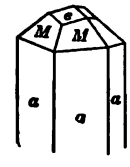


FIG. 50.—Crystal of Proustite with $\infty P2$, $11\bar{2}0$ (*a*), $-\frac{2}{7}R^4$, $35\bar{8}7$ (*M*) and $-\frac{1}{2}R$, $01\bar{1}2$ (*e*).

The cleavage, fracture and hardness of proustite are the same as for pyrargyrite. Its hardness is 2 and its density is about 5.6. The mineral is transparent or translucent. Its color is grayish black by reflected light and scarlet in transparent pieces by transmitted light. Under the long-continued influence of daylight the color deepens until it becomes darker than that of pyrargyrite. Its streak is cinnabar-red to brownish black. Its luster is adamantine. It is a nonconductor of electricity. For sodium light $\omega = 3.0877$, $\epsilon = 2.7924$.

In the closed tube proustite fuses easily and gives a slight sublimate

of white arsenic oxide. In its other chemical properties it resembles pyrargyrite except that it gives reactions for arsenic where this mineral reacts for antimony, and yields only sulphur when dissolved in HNO_3. From its solution in KOH a yellow precipitate of As_2S_3 is thrown down upon the addition of HCl (compare pyrargyrite).

Proustite differs from *pyrargyrite* in its color, transparency and streak, as well as in its arsenic reactions. It is distinguished from *cinnabar* and *cuprite* (CuO) by the arsenic test.

Syntheses.—Crystals of proustite have been produced by reactions analogous to those that yield pyrargyrite, when arsenic compounds are employed in place of antimony compounds.

Occurrence.—The mineral occurs under the same conditions and with the same associates as pyrargyrite and it yields the same alteration products as pyrargyrite.

Localities and Uses.—Handsome crystals of proustite occur at Freiberg and other places in Saxony, at Wolfach in Baden, at Markirchen in Alsace and at Chañarcillo in Chile. It is associated with pyrargyrite and with other ores of silver.

In the western United States it is quite abundant, more particularly in the Ruby district, Colorado, at Poorman lode in Idaho, and in all other localities where pyrargyrite occurs. In many it is mined as an ore of silver.

Bournonite ($(Pb \cdot Cu_2)_3(SbS_3)_2$)

Bournonite is a comparatively rare mineral. It occurs either in compact or granular masses or in well developed crystals of a steel-gray color. It is not of any economic importance except as it may be mixed with other copper compounds exploited for copper.

Analyses of bournonite from two localities are given below:

	S	Sb	As	Pb	Cu	Fe	Total
I.	19.36	23.57	.47	41.95	13.27	.68	99 30
II.	19.78	23.80	...	42.07	12.82	.20	98.67

I. Liskeard, Cornwall, England.
II. Felsöbánya, Hungary.

These analyses are by no means accurate, but they show the composition of the mineral to be approximately Pb, Cu, Sb and S, in which the elements are combined in the following proportions: S = 19.8 per cent; Sb = 24.7 per cent; Pb 42.5 per cent; Cu 13 per cent.

Bournonite crystals are orthorhombic (rhombic bipyramidal class),

with $a : b : c = .9380 : 1 : .8969$. They are usually tabular (Fig. 51), or short, prismatic in habit, and are often in repeated twins (Fig. 52), with wheel-shaped or cross-like forms. The principal planes observed on them are oP(001), P $\bar{\infty}$ (101), P $\breve{\infty}$ (011), $\frac{1}{2}$P(112), ∞ P(110), ∞ P $\bar{\infty}$ (100) and ∞ P $\breve{\infty}$ (010), though 90 or more planes are known. The most common twinning plane is ∞ P(110). Angle $110 \wedge 1\bar{1}0 = 86° 20'$.

The luster of the mineral is brilliant metallic. Its color and streak are steel-gray. Its cleavage is imperfect, parallel to ∞ P $\breve{\infty}$ (010) and its fracture conchoidal or uneven. Its hardness is 2.5–3 and density 5.8. Like most other metallic minerals it is opaque. It is a very poor conductor of electricity.

In the closed tube bournonite decrepitates and yields a dark red sublimate. In the open tube, and on charcoal, it gives reactions for Sb, S, Pb and Cu. When treated with nitric acid it decomposes, producing a

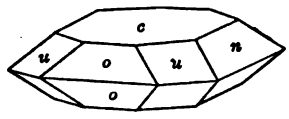


FIG. 51.

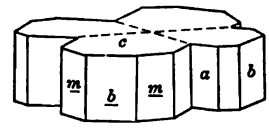


FIG. 52.

FIG. 51.—Bournonite Crystal with oP, 001 (*c*); P $\bar{\infty}$, 101 (*o*); $\frac{1}{2}$P, 112 (*u*) and P $\breve{\infty}$, 011 (*n*).

FIG. 52.—Bournonite Fourling Twinned about ∞ P, 110 (*m*). Form *c* same as in Fig. 51. $b = \infty$ P $\breve{\infty}$ (010) and $a = \infty$ P $\bar{\infty}$ (100).

blue solution of copper nitrate that turns to an intense azure blue when an excess of ammonia is added. In this solution is a residue of sulphur and a white precipitate that contains lead and antimony.

Bournonite is distinguished from most other minerals by its reactions for both antimony and sulphur. From other sulphantimonites it is distinguished by its color, hardness and density.

On long exposure to the atmosphere bournonite alters to the carbonates of lead (cerussite) and copper (malachite and azurite).

Synthesis.—Crystals of bournonite have been obtained by the action of gaseous H_2S on the chlorides and oxides of Pb, Cu and Sb, at moderate temperatures.

Occurrence.—The mineral occurs principally in veins with galena, sphalerite, stibnite, chalcopyrite and tetrahedrite.

Localities.—Good crystals are found in the mines at Neudorf, Harz; at Přibram, in Bohemia; at Felsöbánya, Kapnik and other places in Hungary, and at various places in Chile. In North America it has

been found at the Boggs Mine in Yavapai Co., Ariz., in Montgomery Co., Ark., and at Marmora, Hastings Co., and Darling, Lanark Co., Ontario.

THE SULPHDIARSENITES AND SULPHDIANTIMONITES

A large number of sulpho-salts are apparently salts of acids that contain two or more atoms of As or Sb in the molecule. These acids may be regarded as derived from the ortho acids by the abstraction of H_2S, thus: The arsenious acid containing two atoms of As may be thought of as $2H_3AsS_3 - H_2S = H_4As_2S_5$. Acids with larger proportions of arsenic may be regarded as derived in a similar manner from three or more molecules of the ortho acid. Only a few of these salts are common as minerals. Among the more common are two that are lead salts of derivatives of sulpharsenious and sulphantimonous acids.

Jamesonite ($Pb_2Sb_2S_5$) and Dufrenoysite ($Pb_2As_2S_5$)

Jamesonite and dufrenoysite are lead salts of the acids $H_4Sb_2S_5$ and $H_4As_2S_5$. Both minerals occur in acicular and columnar orthorhombic crystals and in fibrous and compact masses of lead-gray color. Their cleavage is parallel to the base. The minerals are brittle and have an uneven to conchoidal fracture. Their hardness is 2–3 and density 5.5–6. The streak of jamesonite is grayish black, and of dufreynosite reddish brown. Both minerals are easily fusible. They are soluble in HCl with the evolution of H_2S, giving a solution from which acicular crystals of $PbCl_2$ separate on cooling. They are decomposed by HNO_3, with the separation of a white basic lead salt. They are found in veins with antimony and sulphide ores abroad and at several points in Nevada. and in the antimony mines in Sevier Co., Arkansas.

THE SULPHARSENATES AND SULPHANTIMONATES

The sulpharsenates are salts of sulpharsenic acid, H_3AsS_4, and the sulphantimonates, the salts of the corresponding antimony acid, H_3SbS_4. These compounds are much less numerous among the minerals than the sulpharsenites and sulphantimonites. Moreover, no member of the former groups is as common as several of the members of the latter. The most important member is the mineral *enargite* (Cu_3AsS_4) an ortho-sulpharsenate, which in a few places is wrought as a copper ore.

Enargite (Cu_3AsS_4)

Enargite, though a rare mineral, is so abundant at a few points that it has been mined as an ore of copper.

Theoretically, the mineral is S=32.6, As=19.1, Cu=4.83. Most specimens, however, contain an admixture of the isomorphous antimony compound, *famatinite*, and consequently show the presence of antimony. A specimen from the Rarus Mine, Butte, Montana, yielded

S	As	Sb	Cu	Fe	Zn	Ins	Total
31.44	17.91	1.76	48.67	.33	.10	.11	100.32

The mineral crystallizes in the orthorhombic system (bipyramidal class), in crystals with an axial ratio .8694 : 1 : .8308. Their habit is usually prismatic, and they are strongly striated vertically. The crystals are usually highly modified, with the following forms predominating: $\infty P\bar{\infty}$ (100), ∞P(110), $\infty P\breve{2}$(120), $\infty P\breve{3}$(130), $\infty P\breve{\infty}$ (010), and oP(001) (Fig. 53). Stellar trillings, with $\infty P\breve{2}$(120) the twinning plane, have a pseudohexagonal habit. The mineral occurs also in columnar and platy masses.

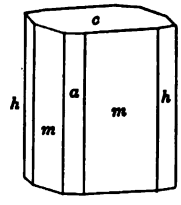


FIG. 53.—Enargite Crystal with ∞P, 110 (*m*); $\infty P\bar{\infty}$, 100 (*a*); $\infty P\breve{\ }$, 120 (*h*) and oP, 001 (*c*).

Enargite possesses a perfect prismatic cleavage and an uneven fracture. It is opaque with a grayish black color and streak. Its hardness is 3 and density 4.4. It is a poor electrical conductor.

It is easily fusible before the blowpipe. When roasted on charcoal it gives the reactions for S and As, and the roasted residue when moistened with HCl imparts to the flame the azure-blue color characteristic of copper. In the closed tube it decrepitates and gives a sublimate of S. When heated to fusion it yields a sublimate of arsenic sulphide. The mineral is soluble in aqua regia.

Enargite is easily recognized by its crystallization and blowpipe reactions.

Occurrence.—Enargite is associated with other copper ores in veins filled by magmatic water at intermediate depths and in a few replacement deposits.

Localities.—Although not widely distributed, enargite occurs in large quantities in the copper mines near Morococha, Peru; Copiapó, Chile; in the province of La Rioja, Argentine; on Luzon, Philippine Islands,

and in the United States, at Butte, Montana; in the San Juan Mountains, Colorado, and in the Tintic District, Utah.

Uses.—It is smelted as an ore of copper. At the Butte smelter it furnishes the arsenic that is separated from the smelter fumes and placed upon the market as arsenic oxide (see p. 113).

THE BASIC SULPHO-SALTS

The basic sulpho-salts are compounds in which there is a greater percentage of the basic elements (metals, etc.), present than is necessary to replace all the hydrogen of the ortho acids. Thus, the copper orthosulpharsenate, enargite, is Cu_3AsS_4 The mineral stephanite is Ag_5SbS_4 and the pure silver polybasite Ag_9SbS_6.

Since three atoms of Ag are sufficient to replace all the hydrogen atoms in the normal acid containing one atom of antimony and the quantities of silver present in stephanite and polybasite are in excess of this requirement, the two minerals are described as basic. The exact relations of the atoms to one another in the molecules are not known.

Although the number of basic sulpho-salts occurring as minerals is large only four are common. These are:

Stephanite	Ag_5SbS_4	Orthorhombic
Polybasite	$(Ag \cdot Cu)_9SbS_6$	Monoclinic
Tetrahedrite	$(R'')_4Sb_2S_7$	Isometric
Tennantite	$(R'')_4As_2S_7$	Isometric

Stephanite (Ag_5SbS_4)

Stephanite, though a comparatively rare mineral, is an important ore of silver in some camps. It occurs massive, in disseminated grains and as aggregates of small crystals. Analyses indicate a composition very close to the requirements of the formula Ag_5SbS_4.

	S	Sb	Ag	As and Cu	Total
Theoretical.....	16.28	15.22	68.50	....	100.00
Crystals, Chañarcillo, Chile	16.02	15.22	68.65	tr	99.89

Stephanite crystallizes in hemimorphic orthorhombic crystals (rhombic pyramidal class), with an axial ratio .6291 : 1 : .6851. The crystals are highly modified, 125 forms having been identified upon them. They have usually the habit of hexagonal prisms, their predominant planes

being $\infty P(110)$ and $\infty P\breve{\infty}(010)$, terminated by $oP(001)$, $P(111)$ and $2P\breve{\infty}(021)$ at one or the other end of the *c* axis (Fig. 54). Twins are common, with $\infty P(110)$ and $oP(001)$ the twinning planes.

The mineral is black and opaque and its streak is black. Its hardness is 2 and density = 6.2 – 6.3. It cleaves parallel to $\infty P\breve{\infty}(010)$ has an uneven fracture, and is a poor conductor of electricity.

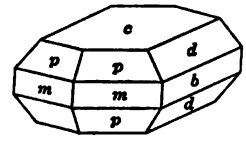


FIG. 54.—Stephanite Crystal with oP, 001 (*c*); $\infty P\breve{\infty}$, 010 (*b*); ∞P, 110 (*m*); $\frac{3}{2}P$, 332 (*p*), $2P\breve{\infty}$, 021 (*d*).

On charcoal stephanite fuses very easily to a dark gray globule, at the same time yielding the white fumes of antimony oxide and the pungent odor of SO_2. Under the reducing flame the globule is reduced to metallic silver. The mineral dissolves in dilute nitric acid and this solution gives a white precipitate with HCl.

Stephanite is easily distinguished from other black minerals by its easy fusibility, its crystallization, and its reactions for Ag, Sb and S.

Localities.—The mineral is associated with other silver ores in the zone of secondary enrichment of veins at Freiberg, Saxony; Joachimsthal and Přibram, Bohemia; the Comstock Lode and other mines in the Rocky Mountain region and at many points in Mexico and Peru.

Uses.—It is mined together with other compounds as an ore of silver. It is particularly abundant in the ores of the Comstock Lode, Nev., and of the Las Chispas Mine, Sonora, Mex.

Polybasite ($(Ag \cdot Cu)_9SbS_6$)

Polybasite is the name usually applied to the mixture of basic sulphantimonites and sulpharsenites of the general formula $R'_9(Sb.As)S_6$, in which $R' = Ag$ and Cu. More properly the name is applied to the antimonite, and the corresponding arsenite is designated as *pearceite*. Several typical analyses follow:

	S	As	Sb	Ag	Cu	Fe	Pb	Ins	Total
I.	17.46	7.56	.....	59.22	15.65	....	...	...	99.89
II.	17.71	7.39	.....	55.17	18.11	1.05	...	.42	99.85
III.	15.43	.50	10.64	68.39	5.13	....	...	...	100.09
IV.	16.37	3.88	5.15	67.95	6.07	....	.76	...	100.18

I. Pearceite, Veta Rica Mine, Sierra Mojada, Mexico.
II. Crystals of pearceite, Drumlummon Mine, Marysville, Montana.
III. Polybasite, Santa Lucia Mine, Guanajuato, Mexico.
IV. Polybasite, Quespisiza, Chile.

The crystallization of the two minerals, which are completely isomorphous, is monoclinic (prismatic class). Their axial ratios are:

Pearceite,	$a : b : c = 1.7309 : 1 : 1.6199$	$\beta = 90° 9'$
Polybasite,	$= 1.7309 : 1 : 1.5796$	$\beta = 90°$

The crystals are commonly tabular or prismatic, with a distinct hexagonal habit. The prominent forms are oP(001), P(111) and 2P $\bar{\infty}$ (20$\bar{1}$). Contact twinning is common, with ∞P(110) the twinning plane, and oP(00$\bar{1}$) the composition plane.

Both minerals are nearly opaque. Except in very thin splinters they are steel-gray to iron-black in color. Very thin plates are translucent and cherry-red. Their streaks are black. Their cleavage is perfect parallel to oP(001) and their fracture uneven. Their hardness is 2–3, and density 6–6.2.

Both minerals are easily fusible. They usually exhibit the reactions for Ag, Sb, As and S.

They are readily distinguished from all other minerals but silver sulpho-salts by their blowpipe reactions. From these they are distinguished by their crystallization. Pearceite and polybasite are distinguished from one another by the relative quantities of As and Sb they contain.

Occurrence.—Both minerals occur in the zone of secondary enrichment in veins of silver sulphides.

Localities.—Polybasite was an important ore of silver in the Comstock Lode, Nevada. It is at present mined with other silver ores at Ouray, Colorado, at Marysville, Montana, at Guanajuato, Mexico, and at various points in Chile. Good crystals occur at Freiberg, Saxony, at Joachimsthal, Bohemia, and in the mines in Colorado, Mexico and Chile.

TETRAHEDRITE GROUP

The name tetrahedrite is given to a mixture of basic sulphantimonites and sulpharsenites crystallizing together in isometric forms with a distinct tetrahedral habit (hextetrahedral class). The isomorphism is so complete that all gradations between the various members of the group are frequently met with. The arsenic-bearing member of the series is known as *tennantite* and the corresponding antimony member as *tetrahedrite*. The latter is the more common.

The following six analyses of tetrahedrite will give some idea of the great range in composition observed in the species.

	S	Sb	As	Cu	Fe	Zn	Ag	Hg	Pb	Total
I.	27.60	25.87	tr	35.85	2.66	5.15	2.30	....	....	99.43
II.	23.51	17.21	7.67	42.00	8.28	.49	.55	....	....	99.71
III.	24.44	27.60	....	27.41	4.27	2.31	14.54	....	....	100.57
IV.	24.89	30.18	tr	32.80	5.85	....	.07	5.57	....	99.36
V.	21.67	24.72	....	33.53	.56	....	1.80	....	16.23	98.51

I. Newburyport, Mass.
II. Cajabamba, Peru.
III. Star City, Nev.
IV. Poracs, Hungary.
V. Arizona.

Upon examination these are found to correspond approximately to the formula $R''_4Sb_2S_7$, in which the R″ is Cu_2, Pb, Fe, Zn, Hg, Ag_2 and sometimes Co and Ni. When R is replaced entirely by copper, the formula ($Cu_8Sb_2S_7$) demands 23.1 per cent S, 24.8 per cent Sb and 52.1 per cent Cu.

Analyses of tennantite yield analogous results that may be represented by the formula $Cu_8As_2S_7$ which demands 26.6 per cent S, 20.76 per cent As and 52.64 per cent Cu.

Analyses of even the best crystallized specimens rarely yield As or Sb alone. Moreover, nearly all show the presence of Zn in notable quantity. The great variation noted in the composition of different specimens which appear to be pure crystals has led to the proposal of other formulas than those given above—some being simpler and others more complex. It is possible that the variation may be explained as due, in part, to some kind of solid solution, rather than as the result solely of isomorphous replacement. It is more probable, however, that it is due to the intergrowth of notable quantities of various sulphides with the sulpho-salts.

There is still considerable confusion in the proper naming of the members of the series, but generally the forms composed predominantly of Cu, Sb and S with or without Zn are known as tetrahedrite and those containing As in place of Sb as tennantite, although several authors confine the use of the latter term to arsenical tetrahedrites containing a notable quantity of iron.

Since the members of the tetrahedrite series often contain a large quantity of metals other than Cu and Zn the group has been so subdivided as to indicate this fact. Thus, there are argentiferous, mercurial and plumbiferous varieties of tetrahedrite. Some of these varieties are utilized as ores of the metals that replace the copper and zinc in the more

common varieties. The relations of the ordinary (II) and the bismuthiferous tennantites (III) to tetrahedrite (I) are shown by the following three analyses:

	S	As	Sb	Bi	Cu	Fe	Ag	Pb	Co	Total
I.	24.48	tr	28.85	.....	45.39	1.32	...	.11	....	100.15
II.	26.61	19.03	.....	.....	51.62	1.95	...	...	....	99.21
III.	29.10	11.44	2.19	13.07	37.52	6.51	.04	...	1.20	101.07

I. Fresney d'Oisans, France.
II. Cornwall, England.
III. Cremenz, Switzerland.

The crystals of both tetrahedrite and tennantite are tetrahedral in habit, the principal forms on them consisting of the simple tetrahedron and complex tetrahedrons such as $\frac{2O2}{2}(211)$, $-\frac{\frac{3}{2}O}{2}(3\bar{3}2)$ together with the dodecahedron, $\infty O(110)$ and the cube, $\infty O \infty (100)$. (Fig. 55.) Twins are common with $O(111)$ the twinning plane. These are sometimes contact twins and sometimes interpenetration twins. Some crystals are very complicated, because of the presence on them of a great number of forms. The total number of distinct forms that have been identified is about 90. The mineral occurs also in granular, dense and earthy masses.

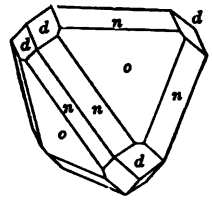


FIG. 55.—Tetrahedrite Crystal with $\frac{O}{2}$. 111 (*o*); ∞O, 110 (*d*) and $\frac{3}{2}O$. 332 (*n*).

The fracture of the tetrahedrites is uneven. Their hardness varies between 3 and 4.5 and their density between 4.4 and 5.1. Their color is between dark gray and iron-black, except in thin splinters, which sometimes exhibit a cherry-red translucency. Their streak is like their color. All tetrahedrites are thermo-electric.

The chemical properties of the different varieties of tetrahedrites vary with the constituents present. All give tests for sulphur and for either antimony or arsenic, and all show the presence of copper in a borax bead. The reactions of other metals that may be present may be learned by consulting pages 483–494.

The crystals of tetrahedrite are so characteristic that there is little danger of confusing the crystallized mineral with other minerals of the same color. The massive forms resemble most clearly *arsenopyrite*, *cobaltite*, *bournonite* and *chalcocite*. From these the tetrahedrites are

best distinguished by their hardness, together with their blowpipe reactions.

Tetrahedrite appears to suffer alteration quite readily, since pseudomorphs of several carbonates and sulphides after tetrahedrite crystals are well known.

Syntheses.—Crystals of the tetrahedrites have been made by passing the vapors of the chlorides of the metals and the chlorides of arsenic or antimony and H_2S through red-hot porcelain tubes. They have also been observed in Roman coins that had lain for a long time in the hot springs of Bourbonne-les-Bains, Haute-Marne, France.

Occurrence.—The tetrahedrites are very common in the zone of secondary enrichment of sulphide veins and in impregnations. They occur associated with chalcopyrite, pyrite, sphalerite, galena and other silver, lead and copper ores in nearly all regions where the sulphide ores of these metals are found. They occur also as primary constituents of veins of silver ores, where they were deposited by magmatic waters.

Localities.—In the United States tetrahedrite occurs at the Kellogg Mines, ten miles north of Little Rock, Arkansas; near Central City and at Georgetown, Colorado; in the Ruby and other mining districts in the same State; at the De Soto Mine in Humboldt Co., Nevada, and at several places in Montana, Utah and Arizona. It is found also in British Columbia and in Mexico, and at Broken Hill, New South Wales.

The arsenical tetrahedrites are not quite as common as is the antimonial variety. Excellent crystals occur in the Cornish Mines, at Freiberg in Saxony, at Skutterud in Norway, and at Capelton, Quebec.

Uses.—The mineral is used to some extent as an ore of silver or of copper, the separation of the metals being effected in the same way as in the case of the sulphides of these substances.

THE SULPHO-FERRITES

Only two sulpho-ferrites are sufficiently important to merit description here. Both of these are copper compounds and both are used as ores of this metal, one—*chalcopyrite*—being one of the most important ores of the metal at present worked.

The first of these minerals discussed, *bornite*, is a basic salt of the acid H_3FeS_3; the second is the salt of the derived acid $HFeS_2$, which may be regarded as the normal acid from which one molecule of H_2S has been abstracted (see p. 116).

Bornite (Cu_5FeS_4)

Bornite, known also as horseflesh ore because of its peculiar purplish-red color, is found usually massive. In Montana and in Chile it constitutes an important ore of copper.

Bornite is probably a basic sulpho-ferrite, though analyses yield results that vary quite widely, especially in the case of massive varieties. This variation is due to the greater or less admixture of copper sulphides, mainly chalcocite, with the bornite. The theoretical composition of the mineral is 25.55 S, 63.27 Cu, and 11.18 Fe. The analyses of a crystallized variety from Bristol, Conn., and of a massive variety from the Bruce Mines, Ontario, follow:

	S	Cu	Fe	Ins	Total
Bristol, Conn	25.54	63.24	11.20	...	99.98
Bruce Mines, Ont	25.39	62.78	11.28	.30	99.75

The crystallization of bornite is isometric (hexoctahedral class), in combinations of ∞ O ∞ (100), ∞ O(110), O(111), and sometimes 2O2(211). Crystals often form interpenetration twins, with O the twinning plane.

The fracture of the mineral is conchoidal, its hardness 3 and density about 5. On fresh fracture the color varies from a copper-red to a purplish brown. Upon exposure alteration rapidly takes place covering the mineral with an iridescent purple tarnish. Its streak is grayish black. It is a good conductor of electricity.

Chemically, the mineral possesses no characteristics other than those to be expected from a compound of iron, copper and sulphur. It dissolves in nitric acid with the separation of sulphur.

It is easily recognized by its purplish brown color on fresh fractures and its purple tarnish.

Bornite alters to chalcopyrite, chalcocite, covellite, cuprite (Cu_2O), chrysocolla ($CuSiO_3 \cdot 2H_2O$) and the carbonates, malachite and azurite. On the other hand, bornite pseudomorphs after chalcopyrite and chalcocite are not uncommon.

Syntheses.—Roman copper coins found immersed in the water of warm springs in France have been partly changed to bornite. Crystals have been formed by the action of H_2S at a comparatively low temperature (100°–200° C.), upon a mixture of Cu_2O, CuO and Fe_2O_3

Occurrence and Origin.—Bornite is usually associated with other copper ores in veins and lodes, where it is in some cases a primary mineral deposited by magmatic waters and in others a secondary mineral produced in the zone of enrichment of sulphide veins. It also sometimes

impregnates sedimentary rocks, where its origin is part due to contact action.

Localities.—The crystallized mineral occurs near Redruth, Cornwall, Eng., and at Bristol, Conn. The massive mineral is found at many places in Norway and Sweden. It is the principal ore of some of the Bolivian, Chilian, Peruvian and Mexican mines and of the Canadian mines near Quebec. In the United States it has been mined at Bristol, Conn., and at Butte, Montana.

Uses.—Bornite is mined with chalcopyrite and other copper compounds as an ore of this metal.

Chalcopyrite ($CuFeS_2$)

From an economic point of view this mineral is the most important of the sulpho-salts, as it is one of the most important ores of copper

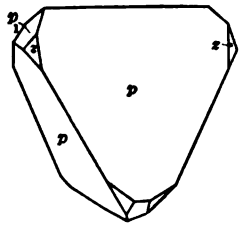


FIG. 56.

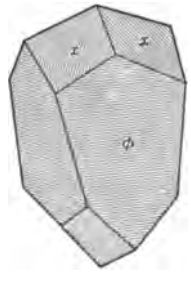


FIG. 57.

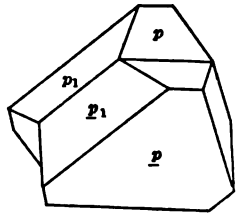


FIG. 58.

FIG. 56.—Chalcopyrite Crystal with P, 111 (p); $-$P, 1$\bar{1}$1 (p) and 2P∞, 201 (z).

FIG. 57.—Chalcopyrite Crystal with $\frac{\frac{7}{2}P}{2}$, 772 (ϕ) and $\frac{P2}{2}$, 212 (χ). The form ϕ sometimes approaches ∞P(110) and χ approaches P∞ (101).

FIG. 58.—Chalcopyrite Twinned about P(111).

known. It occurs both massive and crystallized. From its similarity to pyrite in appearance it is often known as copper pyrites.

Crystallized specimens of chalcopyrite contain 35 per cent S, 34.5 per cent Cu and 30.5 per cent Fe, corresponding to the formula $CuFeS_2$, i.e., a copper salt of the acid $HFeS_2$. The mineral often contains small quantities of intermixed pyrite. It also contains in some instances selenium, thallium, gold and silver.

The crystallization of chalcopyrite is in the sphenoidal, hemihedral division of the tetragonal system (tetragonal scalenohedron class).

The crystals are usually sphenoidal in habit with the sphenoids $\frac{P}{2}(111)$, and $\frac{\frac{3}{2}P}{2}(332)$ the predominant forms (Figs. 56 and 57). In addition to these there are often present also $\infty P \infty (100)$, $\infty P(110)$, $2P \infty (201)$, and a very acute sphenoid that is approximately $\frac{\frac{7}{2}P}{2}(772)$, supposed to be due to the oscillation of $\infty P(110)$ and $\frac{P}{2}(111)$ (Fig. 57). Twins are quite common, with the twinning plane parallel to P (Fig. 58). The plus faces of the sphenoid are often rough and striated, while the minus faces are smooth and even.

The fracture of the mineral is uneven. Its hardness is 3.5–4 and density about 4.2. Its luster is metallic and color brass-yellow. Old fracture surfaces are often tarnished with an iridescent coating. Its streak is greenish black. It is an excellent conductor of electricity.

On charcoal the mineral melts to a magnetic globule. When mixed with Na_2CO_3 and fused on charcoal, a copper globule containing iron results. When treated with nitric acid it dissolves, forming a green solution in which float spongy masses of sulphur. The addition of ammonia to the solution changes it to a deep blue color and at the same time causes a precipitate of red ferric hydroxide.

From the few brassy colored minerals that resemble it, chalcopyrite is distinguished by its hardness and streak.

When subjected to the action of the atmosphere or to percolating atmospheric water chalcopyrite loses its iron component and changes to covellite and chalcocite. The iron passes into limonite. Bornite, copper and pyrite are also frequent products of its alteration. In the oxidation zone of veins it yields limonite, the carbonates, malachite and azurite, and cuprite (Cu_2O). When exposed to the leaching action of water, limonite alone may remain to mark the outcrop of veins, the copper being carried downward in solution to enrich the lower portions of the vein. The deposit of limonite on the surface is known as "gossan."

Syntheses.—Crystals of chalcopyrite have been produced by the action of H_2S upon a moderately heated mixture of CuO and Fe_2O_3 enclosed in a glass tube. The mineral has also been made by the action of warm spring waters upon ancient copper coins. It is also a fairly common product of roasting-oven operations.

Occurrence and Origin.—Chalcopyrite is widely disseminated as a primary vein mineral, and is often found in nests in crystalline rocks.

It also impregnates slates and other sedimentary rocks, schists and altered igneous rocks where, in some cases, it is a contact deposit and in others is original. It is also formed by secondary processes causing enrichment of copper sulphide veins. Its most common associates are galena, sphalerite and pyrite. It is the principal copper ore in the Cornwall mines, where it is associated with cassiterite (SnO_2), galena and other sulphides. It is also the important copper ore of the deposits of Falun, Sweden, of Namaqualand in South Africa, those near Copiapó in Chile, those of Mansfeld, Germany, of the Rio Tinto district in Spain, of Butte and other places in Montana, and of the great copper-producing districts in Arizona, Utah and Nevada.

Crystals occur near Rossie, Wurtzboro and Edenville, N. Y., at the French Creek Mines, Chester Co., Penn., near Finksburg, Md., and at many other places.

Extraction.—The mineral is concentrated by mechanical methods. The concentrates are roasted at a moderately high temperature, the iron being transformed into oxides and the copper partly into oxide and partly into sulphide. Upon further heating with a flux the iron oxide unites with this to form a slag and the copper sulphide melts, and collects at the bottom of the furnace as "matte," which consists of mixed copper and copper sulphide. This is roasted in a current of air to free it from sulphur. By this process all of the copper is transformed into the oxide, which may be converted into the metal by reduction. The metal is finally refined by electrical processes. Much of the copper obtained from chalcopyrite contains silver or gold, or both, which may be recovered by any one of several processes.

Uses.—A large portion of the copper produced in the world is obtained by the smelting of chalcopyrite and the ores associated with it.

Production.—The world's total product of copper has been referred to in another place (p. 55). Of this total (2,251,300,000 lb.) the United States supplied, in 1912, 1,243,300,000 lb., of which about 1,000,000,000 lb. were obtained from sulphide ores. Arizona and Montana produced the greater portion of this large quantity, the former contributing about 359,000,000 lb. to the aggregate, and the latter 308,800,000 lb. Outside of the United States the most important copper-producing countries are Mexico, Japan, Spain and Portugal, Australia, Chile, Canada, Russia, Peru and Germany, in the order named. Practically all of this copper, except that from Japan and Mexico, is extracted from sulphide ores.

CHAPTER VI

THE CHLORIDES, BROMIDES, IODIDES AND FLUORIDES

THE salts belonging to this group are compounds of metals with hydrochloric (HCl), hydrobromic (HBr), hydriodic (HI) and hydrofluoric (HF) acids. Only a few are of importance. Of these some are simple chlorides, others are simple fluorides, others are double chlorides or fluorides (i.e. cryolite, AlF_3+3NaF), and others are double hydroxides and chlorides (atacamite).

THE CHLORIDES

The simple chlorides crystallize in the isometric system, but in different classes in this system. They comprise salts of the alkalies, K, Na and NH_4, and of silver. Of these only three minerals are of importance, viz.: *sylvite, halite* and *cerargyrite.*

Halite (NaCl)

Halite, or common salt, is the best known and most abundant of the native chlorides. It is a colorless, transparent mineral occurring in crystals, and in granular and compact masses.

Pure halite consists of 39.4 per cent Cl and 60.6 per cent Na. The mineral usually contains as impurities clay, sulphates and organic substances. The several analyses quoted below indicate the nature of the commonest impurities and their abundance in typical specimens.

	NaCl	CaCl	MgCl	$CaSO_4$	Na_2SO_4	Mg_2SO_4	Clay	H_2O
I.	97.35	....	....	1.01	.43	.23	....	.30
II.	90.3	....	....	5.00	2.00	....	2.00	.70
III.	98.88	tr	tr	.79	....	....	....	.33

I. Stassfurt, Germany.
II. Vic, France.
III. Petit Anse, La.

The crystallization of halite is isometric (hexoctahedral class), the principal forms being $\infty O \infty$ (100), O(111) and ∞O(110). Often the

faces of the forms are hollowed or depressed giving rise to what are called "hopper crystals" (Fig. 59). The mineral occurs also in coarse, granular aggregates, in lamellar and fibrous masses and in stalactites.

Its cleavage is perfect parallel to $\infty O \infty$ (100). Its fracture is conchoidal. Its hardness is 2–2.5 and density about 2.17. Halite, when pure, is colorless, but the impurities present often color it red, gray, yellow or blue. The bright blue mottlings observed in many specimens are thought to be due to the presence of colloidal sodium. The mineral is transparent or translucent and its luster is vitreous. Its streak is colorless. Its saline taste is well known. It is diathermous and is a nonconductor of electricity. The mineral is plastic under pressure, and its plasticity increases with the temperature. Its index of refraction for sodium light, $n = 1.5442$.

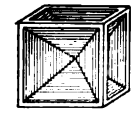


FIG. 59.—Hopper-Shaped Cube of Halite.

In the closed tube halite fuses and often it decrepitates. When heated before the blowpipe it fuses (at 776°) and colors the flame yellow. The chlorine reaction is easily obtained by adding a small particle of the mineral to a microcosmic salt bead that has been saturated with copper oxide. This, when heated before the blowpipe, colors the flame a brilliant blue. The mineral easily dissolves in water, and its solution yields an abundant white precipitate with silver nitrate.

The solubility of halite is accountable for a large number of pseudomorphs. The crystals embedded in clays are gradually dissolved, leaving a mold that may be filled by other substances, which thus become pseudomorphs.

Syntheses.—Crystals of halite have been produced by sublimation from the gases of furnaces, and by crystallization from solution containing sodium chloride.

Occurrence and Origin.—Salt occurs most abundantly in the water of the ocean, of certain salt lakes, of brines buried deep within the rocks in some places, and as beds interstratified with sedimentary rocks. In the latter case it is associated with sylvite (KCl), anhydrite ($CaSO_4$), gypsum ($CaSO_4 \cdot 2H_2O$), etc., which, like the halite, are believed to have been formed by the drying up of salt lakes or of portions of the ocean that were cut off from the main body of water, since the order of occurrence of the various beds is the same as the order of deposition of the corresponding salts when precipitated by the evaporation of sea water at varying temperatures. (Comp. pp. 22, 23.)

Below are given figures showing the composition of the salts in the water of the ocean, of Great Salt Lake, and of the Syracuse, N. Y., and

Michigan artificial brines (produced by forcing water to the buried rock salt).

	NaCl	$CaCl_2$	$MgCl_2$	NaBr	KCl	Na_2SO_4	K_2SO_4	$CaSO_4$	$MgSO_4$
I.	77.07	....	7.86	1.30	3.89	....	....	4.63	5.29
II.	79.57	....	10.00	....	....	6.25	3.60	.58	
III.	95.97	.90	.69	....	....	....	....	2 54	
IV.	91.95	3.19	2 48	....	....	....	....	2.39	

I. Atlantic Ocean.
II. Great Salt Lake.
III. New York brines.
IV. Michigan brines.

Localities.—The principal mines of halite, or rock salt, are at Wieliczka, Poland; Hall, Tyrol; Stassfurt, Germany, where fine crystals are found; the Valley of Cardova, Spain; in Cheshire, England and in the Punjab region of India. At Petit Anse in Louisiana, in the vicinity of Syracuse, N. Y., and in the lower peninsula of Michigan thick beds of the salt are buried in the rocks far beneath the surface. Much of the salt is comparatively pure and needs only to be crushed to become usable. In most cases, however, it is contaminated with clay and other substances. In these cases it must be dissolved in water and recrystallized before it is sufficiently pure for commercial uses.

The best known deposits are at Stassfurt where there is a great thickness of alternating layers of halite, sylvite (KCl), anhydrite, gypsum, kieserite ($MgSO_4 \cdot H_2O$) and various double chlorides and sulphates of potassium and magnesium. Although the halite is in far greater quantity than the other salts, nevertheless, the deposit owes most of its value to the latter, especially the potassium salts (comp. pp. 137, 142).

Uses.—Besides its use in curing meat and fish, salt is employed in glazing pottery, in enameling, in metallurgical processes, for clearing oleomargarine, making butter and in the more familiar household operations. It is also the chief source of sodium compounds.

Production.—Most of the salt produced in the United States is obtained directly from rock salt layers by mining or by a process of solution, in which water is forced down into the buried deposit and then to the surface as brine, which is later evaporated by solar or by artificial heat. In the district of Syracuse, N. Y., salt occurs in thick lenses interbedded with soft shales. In eastern Michigan and in Kansas salt is obtained from buried beds of rock salt, and in Louisiana from great dome-like plugs covered by sand, clay and gravel. Some of the masses in this State are 1,756 ft. thick.

The salt production of the United States for 1912 amounted to 33,324,000 barrels of 280 lb. each, valued at $9,402,772. Of this quantity 7,091,000 barrels were rock salt.

The imports of all grades of salt during the same time were about 1,000,000 barrels and the exports about 440,000 barrels.

Sylvite (KCl)

Sylvite is isometric, like halite, but the etched figures that may be produced on the faces of its crystals indicate a gyroidal symmetry (pentagonal icositetrahedral class). The habit of the crystals is cubic with O(111) and ∞O∞ (100) predominating.

Pure sylvite contains 47.6 per cent Cl and 52.4 per cent K, but the mineral usually contains some NaCl and often some of the alkaline sulphates.

The physical properties of sylvite are like those of halite, except that its hardness is 2 and the density 1.99. Its melting temperature is 738° and n for sodium light = 1.4903.

When heated before the blowpipe the mineral imparts a violet tinge to the flame, which can be detected when masked by the yellow flame of sodium by viewing it through blue glass. Otherwise sylvite and halite react similarly.

Halite and sylvite are distinguished from other soluble minerals by the reaction with the bead saturated with copper oxide, and from one another by the color imparted to the blowpipe flame.

Synthesis.—Sylvite crystals have been made by methods analogous to those employed in syntheses of halite crystals.

Occurrence.—Sylvite occurs associated with halite, but in distinct beds, at Stassfurt, Germany, and at Kalusz, Galicia. It has also been found, together with the sodium compound, incrusting the lavas of Vesuvius.

Uses.—Sylvite is an important source of potassium salts, large quantities of which are used in the manufacture of fertilizers.

CERARGYRITE GROUP

The cerargyrite group comprises the chloride, bromide and iodide of silver. The first two exist as the minerals *cerargyrite* and *bromargyrite*, both of which crystallize in the isometric system. The isometric AgI exists only above 146°; below this temperature the iodide is hexagonal. The hexagonal modification occurs as the mineral *iodyrite*, which, of course, is not regarded as a member of the cerargyrite group.

Cerargyrite (AgCl)

Cerargyrite, or horn silver, is an important silver ore. It is usually associated with other silver compounds, the mixture being mined and smelted without separation of the components. It is usually recognizable by its waxy, massive character.

Silver chloride consists of 24.7 per cent chlorine and 75.3 per cent silver, but cerargyrite often contains, in addition to its essential constituents, some mercury, bromine and occasionally some iodine. Crystals are rare. They are isometric (hexoctahedral class), with a cubical habit, their predominant forms being $\infty O \infty$ (100), ∞O(110), O(111), 2O(221) and 2O2(211). Twins sometimes occur with O(111) the twinning face. The mineral is sometimes found massive, embedded among other minerals, but is more frequently in crusts covering other substances.

The fracture of cerargyrite is conchoidal. The mineral is sectile. Its hardness is 1–1.5 and density about 5.5. Its color is grayish, white or yellow, sometimes colorless. On exposure to light it turns violet-brown. It is transparent to translucent and its streak is white. It is a very poor conductor of electricity. Like halite it is diathermous. n for sodium light = 2.071.

In the closed tube cerargyrite fuses without decomposition. On charcoal it yields a metallic globule of silver, and when heated with oxide of copper in the blowpipe flame it gives the chlorine reaction. The mineral is insoluble in water and in nitric acid but is soluble in ammonia, and potassium cyanide. When a particle of the mineral is placed on a sheet of zinc and moistened with a drop of water, it swells, turns black and is finally reduced to metallic silver, which, when rubbed by a knife blade, exhibits the white luster of the metal.

Cerargyrite is easily distinguished from all other minerals, except the comparatively rare bromide and iodide, by its physical properties and by the metallic globule which it yields on charcoal.

Syntheses.—Crystals of cerargyrite have been obtained by the rapid evaporation of ammoniacal solutions of silver chloride, and by the cooling of solutions of the chloride in molten silver iodide.

Occurrence.—The mineral occurs in the upper (oxidized) portions of veins of argentiferous minerals, where it is associated with native silver and oxidized products of various kinds.

Localities.—The most important localities of cerargyrite are in Peru, Chile, Honduras and Mexico, where it is associated with native silver. It is also found near Leadville, Colo.; near Austin, in the Comstock lode, Nev., and at the Poorman Mine, and in other mines in Idaho

and at several places in Utah. Good crystals occur in the Poorman Mine.

Extraction.—When a silver ore consists essentially of cerargyrite the metal may be extracted by amalgamation. Ores containing comparatively small quantities of cerargyrite are smelted.

Production.—The quantity of cerargyrite mined cannot be safely estimated. As has been stated, it is usually wrought with other silver ores.

THE FLUORIDES

The fluorides are salts of hydrofluoric acid. There are several known to occur as minerals, but only two, the fluoride of calcium and

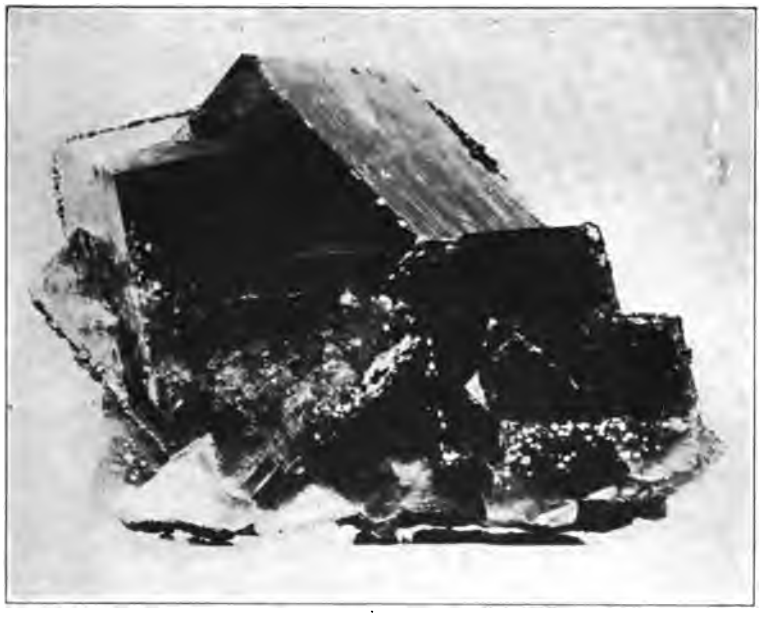


FIG 60.—Group of Fluorite Crystals from Weardale, Co., Durham, England. (*Foote Mineral Company.*)

the double fluorides of sodium and aluminium are of sufficient importance to merit description here.

Fluorite (CaF_2)

Fluorite, or fluorspar, is the principal source of fluorine. It is usually a transparent mineral that is characterized by its fine color and its hand-

some crystals (Fig. 60). Perhaps there is no other mineral known that can approach it in the beauty of its crystal groups. The uncrystallized fluorite may be massive, granular or fibrous.

Fluorite is a compound of Ca and F in the proportion of 48.9 per cent F and 51.1 per cent Ca. Chlorine is occasionally present in minute quantities, and SiO_2, Al_2O_3 and Fe_2O_3 are always present. A sample of commercially prepared fluorite from Marion, Ky., gave:

CaF_2	SiO_2	$Al_2O_3+Fe_2O_3$	$CaCO_3$	MgO
94.72	1.22	.98	1.82	.68

The crystallization is isometric (hexoctrahedral class), and interpenetration twins are frequent. The principal forms observed are

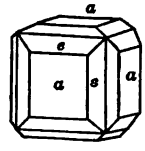


FIG. 61.

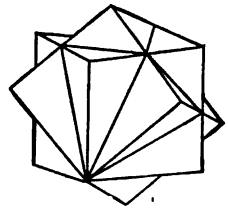


FIG. 62.

FIG. 61.—Crystal of Fluorite with ∞O∞, 100 (*a*) and ∞O2, 210 (*e*).
FIG. 62.—Interpenetration Cubes of Fluorite, Twinned about O(111).

O(111), ∞O∞ (100), ∞O2(210) and 4O2(421) (Fig. 61), but some crystals are highly modified, as many as 58 forms having been identified upon the species. The twins, with O(111) the twinning plane, are usually interpenetration cubes, or cubes modified on the corners by the octahedrons (Fig. 62). The mineral occurs also in granular, fibrous and earthy masses.

The cleavage of fluorite is perfect parallel to O(111). The mineral is brittle, its fracture is uneven or conchoidal, its hardness is 4 and its density about 3.2. It melts at 1387°. Its color is some shade of yellow, white, red, green, blue or purple, its luster vitreous, and its streak is white. Many specimens are transparent, some are only translucent. Most specimens phosphoresce upon heating. A variety that exhibits a green phosphoresence is known as *chlorophane*. The index of refraction for sodium light is 1.43385 at 20°. The mineral is a nonconductor of electricity.

The color of the brightly tinted varieties was formerly thought to be due to the presence of minute traces of organic substance since it is lost

or changed when the mineral is heated, but recent observations of the effect of radium emanations upon light-colored specimens indicate a deepening of their color by an increase in the depth of the blue tints. This suggests that the coloring matter is combined with the CaF_2. It may be a colloidal substance.

In the closed tube fluorite decrepitates and phosphoresces. When heated on charcoal it fuses, colors the flame yellowish red and yields an enamel-like residue which reacts alkaline to litmus paper. Its powder treated with sulphuric acid yields hydrofluoric acid gas which etches glass. The same effect is produced when the powdered mineral is fused with four times its volume of acid potassium sulphate ($HKSO_4$) in a glass tube. The walls of the tube near the mixture become etched as though acted upon by a sand blast.

Fluorite is easily distinguished by its cleavage and hardness from most other minerals. It is also characterized by the possession of fluorine for which it gives clear reactions.

Syntheses.—Crystals are produced upon the cooling of a molten mixture of CaF_2 and the chlorides of the alkalies, and by heating amorphous CaF_2 with an alkaline carbonate and a little HCl in a closed tube at 250°.

Occurrence, Localities and Origin.—The mineral occurs in beds, in veins, often as the gangue of metallic ores and as crystals on the walls of cavities in certain rocks. It is the gangue of the lead veins of northern England and elsewhere. Handsome crystallized specimens come from Cumberland and Derbyshire, England; Kongsberg, Norway; Cornwall, Wales, and from the mines of Saxony. In the United States the mineral forms veins on Long Island; in Blue Hill Bay, Maine; at Putney, in Vermont; at Plymouth, Conn.; at Lockport and Macomb, in New York; at Amelia Court House, Va., and abundantly in southeastern Illinois and the neighboring portion of Kentucky, where it occurs associated with zinc and lead ores. These last-named localities, the neighborhood of Mabon Harbor, Nova Scotia, and Thunder Bay, Lake Superior, afford excellent crystal groups. In nature fluorite has been apparently produced both by crystallization from solutions and by pneumatolytic processes.

Since fluorite is soluble in alkaline waters, its place in the rocks is often occupied by calcite, quartz or other minerals that pseudomorph it.

Uses.—The mineral is used extensively as a flux in smelting iron and other ores, in the manufacture of opalescent glass, and of the enamel coating used on cooking utensils, etc. It is also used in the manufacture of hydrofluoric acid, which, in turn, is employed in etching glass. The brighter colored varieties are employed as material for vases and the

transparent, colorless kinds are ground into lenses for optical instruments. The mineral is also cut into cheap gems, known according to color, as false topaz, false amethyst, etc. Except when used for making lenses or as a precious stone, fluorite is prepared for shipment by crushing, washing and screening. A portion is ground.

Production.—The fluorite produced in the United States is obtained mainly from Illinois and Kentucky, though small quantities are mined in Colorado, New Mexico and New Hampshire. The production in 1912 amounted to 116,545 tons, valued at $769,163. Of this, 114,410 tons came from Illinois and Kentucky. The imports were 26,176 tons, valued at $71,616.

THE DOUBLE CHLORIDES AND DOUBLE FLUORIDES

These double salts are apparently molecular compounds, in which usually two chlorides or two fluorides combine, as in AlF_3+3NaF. Moreover, one of the members of the combination of chlorides is nearly always either the sodium or the potassium chloride. The law of this combination is expressed by Professor Remsen in these words: "The number of molecules of potassium or sodium chloride which combine with another chloride is limited by the number of chlorine atoms contained in the other chloride." Thus, if NaCl makes double salts with MCl_2, in which M represents any bivalent element, only two are possible, viz: MCl_2+NaCl and $MCl_2+2NaCl$. With MCl_3 three double salts with sodium may be formed, etc. These double salts are not regarded as true molecular compounds, but they are looked upon as compounds in which Cl and F are bivalent like oxygen.

Carnallite ($KMgCl_3 \cdot 6H_2O$)

Carnallite may be regarded as a hydrated double chloride of the composition $MgCl_2 \cdot KCl \cdot 6H_2O$ with 14.1 per cent K, 8.7 per cent Mg, 38.3 per cent Cl and 39.0 per cent H_2O. It occurs in distinct crystals but more frequently in massive granular aggregates.

Its crystallization is orthorhombic (bipyramidal class), but the habit of its crystals is usually hexagonal because of the nearly equal development of pyramids and brachydomes. Its axial ratio is .5891 : 1 : 1.3759. Crystals are commonly bounded by $\infty P(110)$, $P(111)$, $\frac{1}{2}P(112)$, $\frac{1}{3}P(113)$, $\infty P\breve{\infty}(010)$, $2P\breve{\infty}(021)$, $P\breve{\infty}(011)$, $\frac{2}{3}P\breve{\infty}(023)$, $oP(001)$, and $P\bar{\infty}(101)$. The angle $110 \wedge 1\bar{1}0 = 61° 20\frac{1}{3}'$.

Carnallite is colorless to milky white, transparent or translucent, and has a fatty luster. Many varieties appear red in the hand specimens

because of the inclusion of numerous small plates of hematite or goethite, or yellow because of inclusions of yellow liquids or tiny crystals. The mineral has a hardness of 1–3, and a density of 1.60. It possesses no cleavage but has a conchoidal fracture. It is not an electrical conductor. It is deliquescent and has a bitter taste. Its indices of refraction for sodium light are $\alpha = 1.467$, $\beta = 1.475$, $\gamma = 1.494$.

Before the blowpipe carnallite fuses easily. In the closed tube it becomes turbid and gives off much water, which is frequently accompanied by the odor of chlorine. It melts in its own water of crystallization. When evaporated to dryness and heated by the blowpipe flame a white mass results which is strongly alkaline. The mineral dissolves in water, forming a solution which reacts for Mg, K and Cl.

Carnallite is easily recognized by its solubility, its bitter taste and the reaction for chlorine.

Synthesis.—The mineral separates in measurable crystals from a solution of $MgCl_2$ and KCl.

Occurrence and Origin.—Carnallite occurs in beds associated with sylvite, halite, kieserite (p. 246), and other salts that have been precipitated by the evaporation of sea water or the water of salt lakes.

Localities.—It is found in large quantity at Stassfurt, Germany; at Kalusz, in Galicia and near Maman, in Persia.

Uses.—Carnallite is used as a fertilizer and as a source of potash salts.

Cryolite (Na_3AlF_6)

Cryolite usually occurs as a fine-grained granular white mass in which are often embedded crystals of light brown iron carbonate (siderite). The formula given above demands 54.4 per cent F, 12.8 per cent Al and 32.8 per cent Na. Analyses of pure white specimens correspond very closely to this.

The mineral is monoclinic (prismatic class), but crystals are exceedingly rare and when found they have a cubical habit. Their axial ratio is $a : b : c = .9662 : 1 : 1.3882$. $\beta = 89° 49'$. The principal forms are $\infty P(110)$, $oP(001)$, $P\bar{\infty}(0\bar{1}0)$, $-P\bar{\infty}(010)$ and $P\breve{\infty}(100)$, thus resembling the combination of the cube and octahedron. Twins are common, with $\infty P(110)$ the twinning plane.

The cleavage of cryolite is perfect parallel to $oP(001)$. Its fracture is uneven. Hardness is 2.5 and density about 3. Its color is snow-white inclining to red and brown. Its luster is vitreous or greasy and the mineral is translucent to transparent. Because of its low index of refraction, massive specimens suggest masses of wet snow. The re-

fractive index β for sodium light is 1.364. It is a nonconductor of electricity.

Cryolite is very easily fusible, small pieces melting even at the low temperature of a candle flame. The mineral is soluble in sulphuric acid with the evolution of HF. When fused in the closed tube with $KHSO_4$ it yields hydrofluoric acid, and when fused on charcoal fluorine is evolved. The residue treated with $Co(NO_3)_2$ and heated gives the color reaction for Al.

By the aid of its reactions with sulphuric acid, its fusibility and its physical properties cryolite is easily distinguished from *fluorite*, which it most resembles, and from all other minerals.

Occurrence, Localities and Origin.—The occurrences of cryolite are very few. It has been found in small quantities near Miask in the Ilmen Mts., Russia; near Pike's Peak, Colo., and in the Yellowstone National Park. Its principal occurrence is in a great pegmatitic vein cutting granite near Ivigtut, Greenland, whence all the mineral used in the arts is obtained. The associates of the cryolite at this place are siderite, galena, chalcopyrite, pyrite, fluorite, topaz and a few rare minerals. The vein is said to be intrusive into the granite. It is believed to be a magmatic concentration.

Uses.—Cryolite was formerly employed principally in the manufacture of alum and of salts of sodium. At present it is used as a flux in the electrolytic production of aluminium, and is employed in the manufacture of white porcelain-like glass, and in the process of enameling iron. The mineral is quarried in Greenland and imported into the United States to the extent of about 2,500 tons annually. Its value is about $25 per ton.

THE OXYCHLORIDES

The oxychlorides are combinations of hydroxides and chlorides. Some of them are "double salts" in the sense in which this word is explained above. *Atacamite* is a combination of the oxychloride $Cu(OH)Cl$ with the hydroxide $Cu(OH)_2$, or $\begin{matrix} HO \\ Cl \end{matrix}\!\!>\!Cu \cdot Cu(OH)_2$.

Atacamite ($Cu(OH)Cl \cdot Cu(OH)_2$)

Atacamite is especially abundant in South America. The mineral is usually found in crystalline, fibrous or granular aggregates of a bright green color.

Analyses of specimens from Australia and from Atacama, Chile, yield:

	Cl	Cu	CuO	H_2O	Total
Australia.....	16.44	14.67	56.64	12.02	99.77
Atacama, Chile.....	15.83	14.16	55.70	14.31	100.00

The formula requires 16.6 per cent Cl, 14.9 per cent Cu, 55.8 per cent CuO and 12.7 per cent H_2O.

The crystallization of atacamite is orthorhombic (bipyramidal class), with $a : b : c = .6613 : 1 : .7529$. Its crystals are usually slender prisms bounded by $\infty P(110)$, $\infty P\breve{2}(120)$, $\infty P\breve{\infty}(010)$, $P\breve{\infty}(011)$, $oP(001)$ and $P(111)$, or tabular forms flattened in the plane of the macropinacoid $\infty P\bar{\infty}(100)$. Twins are common, with the twinning plane $\infty P(110)$.

The cleavage of atacamite is perfect parallel to $\infty P\breve{\infty}(010)$. Its fracture is conchoidal. Its hardness is 3–3.5 and density about 3.76. Pure atacamite is of some shade of green, varying between bright shades and emerald. Its aggregates often contain red or brown streaks or grains due to the admixture of copper oxides. It is transparent to translucent. The streak of the mineral is apple-green. It is a nonconductor of electricity. Its indices of refraction for green light are: $\alpha = 1.831$, $\beta = 1.861$, $\gamma = 1.880$.

In the closed tube atacamite gives off much water with an acid reaction, and yields a gray sublimate. In the oxidizing flame it fuses and tinges the flame azure blue (reaction for copper chloride). It is easily reduced to a globule of copper on charcoal and is easily soluble in acids.

Atacamite is readily distinguished from *garnierite*, *malachite* and other green minerals by its solubility in acids without effervescence and by the azure blue color it imparts to the flame.

Synthesis.—Crystals have been produced by heating cuprous oxide (Cu_2O) with a solution of $FeCl_3$, in a closed tube at 250°.

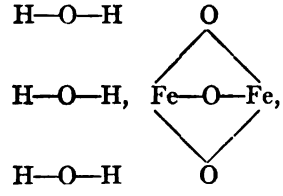
Occurrence, Localities and Origin.—The mineral is most abundant along the west side of the Andes Mountains in Chile and Bolivia. It occurs also in South Australia; in India; at Ambriz, on the west coast of Africa; in southern Spain; in Cornwall, where it forms stalactite tubes; in southern California, and near Jerome, Arizona. It is formed as the result of the alteration of other copper compounds, and is found most abundantly in the upper portions of copper veins. Atacamite changes on exposure to the weather into the carbonate, malachite, and the silicate, chrysocolla.

Uses.—The mineral is an important ore of copper, but it is mined with other compounds and consequently no records of the quantity obtained are available.

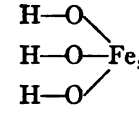
CHAPTER VII

THE OXIDES

THE oxides (except water) and the hydroxides may be regarded as derivatives of water, the hydrogen being replaced wholly or in part by a metal. When only part of the hydrogen is replaced an hydroxide results; when all of the hydrogen is replaced an oxide results. Thus, sodium hydroxide, NaHO, may be looked upon as H_2O, in which Na has replaced one atom of H, and sodium oxide, Na_2O, as H_2O in which both hydrogen atoms have been replaced by this element. Ferric oxide and ferric hydroxide bear these relations to water:



ferric oxide, Fe_2O_3



ferric hydroxide. $Fe(OH)_3$

The oxides constitute a very important, though not a large, class of minerals. Some of them are among the most abundant of all minerals. They are separated into the following groups: Monoxides, sesquioxides, dioxides and higher oxides.

THE MONOXIDES

Ice (H_2O)

The properties of ice are so well known that they need no special description in this place. The mineral is never pure, since it contains, in all cases, admixtures of various soluble salts. Its crystallization is hexagonal and probably trigonal and hemimorphic (ditrigonal pyramidal class). Crystals are often prismatic, as when ice forms the covering of water surfaces, or the bodies known as hailstones. In the form of snow the crystals are often stellate, or skeleton crystals, and sometimes

hollow prisms. The principal forms observed on ice crystals are $0P(0001)$ $\infty P(10\bar{1}0)$, $\frac{1}{2}P(10\bar{1}2)$, $P(10\bar{1}1)$ and $4P(40\bar{4}1)$ (Fig. 63).

The hardness of ice is about 1.5 and its density .9181. It is transparent and colorless except in large masses when it appears bluish. Its fracture is conchoidal. It possesses no distinct cleavage. Its fusing

FIG. 63.—Photographs of Snow Crystals, Magnified about 15 Diameters. (*After Bentley and Perkins.*)

point is 0° and boiling point 100°. It is a poor conductor of electricity. Its indices of refraction for sodium light at 8° are: $\omega = 1.3090$, $\epsilon = 1.3133$.

COPPER OXIDES

There are two oxides of copper, the red cuprous oxide (Cu_2O) and the black cupric oxide (CuO). Both are used as ores, the former being much more important a source of the metal than the latter.

Cuprite (Cu_2O)

Cuprite occurs in crystals, in granular and earthy aggregates and massive. The mineral is usually reddish brown or red and thus is easily distinguished from most other minerals. Its composition when pure is 88.8 per cent Cu and 11.2 per cent O.

In crystallization the mineral is isometric, in the gyroidal hemihedral division of the system (pentagonal icositetrahedral class). Its pre-

dominant forms are $\infty O \infty$ (100), O(111), ∞O(110), $\infty O2$(210), 2O2(211), 2O(221) and $3O\frac{3}{2}$(321), sometimes lengthened out into capillary crystals, producing fibrous varieties (var. *chalcotrichite*).

The cleavage of cuprite is fairly distinct parallel to O(111). Its fracture is uneven or conchoidal. Its hardness is 3.5–4 and density about 6. The mineral is in some cases opaque; oftener it is translucent or even transparent in very thin pieces. By reflected light its color is red, brown and occasionally black. By transmitted light it is crimson. When gently heated transparent varieties turn dark and become opaque, but they reassume their original appearance upon cooling. Its streak is brownish red and has a brilliant luster. When rubbed it becomes yellow and finally green. The luster of the mineral varies between earthy and almost vitreous. It is a poor conductor of electricity, but its conductivity increases rapidly with rising temperature. Its refractive index for yellow light = 2.705.

In the blowpipe flame cuprite fuses and colors the mantle of the flame green. If moistened with hydrochloric acid before heating the flame becomes a brilliant azure blue. On charcoal the mineral first fuses and then is reduced to a globule of metallic copper. It dissolves in strong hydrochloric acid, forming a solution which, when cooled and diluted with cold water, yields a white precipitate of cuprous chloride (Cu_2Cl_2).

Cuprite may easily be distinguished from other minerals possessing a red streak by the reaction for copper—such as the production of a metal globule on charcoal, and the formation of cuprous chloride in concentrated hydrochloric acid solutions by the addition of water. Moreover, the mineral is softer than *hematite* and harder than *reaglar*, *cinnabar* and *proustite*.

Cuprite suffers alteration very readily. It may be reduced to native copper, in which case the copper pseudomorphs the cuprite, or, on exposure to the air it may be changed into the carbonate, malachite, pseudomorphs of which after cuprite are common.

Syntheses.—Crystals of cuprite have frequently been observed on copper utensils and coins that had been buried for long periods of time. Crystals have also been obtained by long-continued action of NH_3 upon a mixture of solutions of the sulphates of iron and copper, and by heating a solution of copper sulphate and ammonia with iron wire in a closed tube.

Occurrence, Origin and Localities.—Cuprite often occurs as well defined crystals embedded in certain sedimentary rocks in the upper, oxidized portions of copper veins, and in masses in the midst of other copper ores, from which it was produced by oxidation processes. It is

found as crystals in Thuringia, in Tuscany, on the island of Elba, in Cornwall, Eng., at Chessy, France; and near Coquimbó, in Chile. In Chile, in Peru, and in Bolivia it exists in great masses.

In the United States it occurs at Cornwall, Lebanon Co., Penn. It is also found associated with the native copper on Keweenaw Point, Mich.; at the copper mines in St. Genevieve Co., Mo.; at Bisbee and at other places in Arizona. The fibrous variety known as *chalcotrichite* is beautifully developed at Morenci in the same State.

Uses.—Cuprite is mined with other copper compounds as an ore of copper.

Melaconite, or Tenorite (CuO)

Melaconite, or tenorite, is less common than cuprite. It usually occurs in massive forms or in earthy masses. Crystals are rare. Its composition is 79.8 per cent Cu and 20.2 per cent O.

In crystallization melaconite is triclinic with a monoclinic habit. Its axial ratio is $a : b : c = 1.4902 : 1 : 1.3604$ and $\beta = 99° 32'$. The angles α and γ are both 90°, but the optical properties of the crystals proclaim their triclinic symmetry.

The mineral possesses an easy cleavage parallel to oP(001). Its fracture is conchoidal and uneven, its hardness 3 to 4 and density about 6. When it occurs in thin scales its color is yellowish brown or iron gray. When massive or pulverulent it is dull black. Its streak is black, changing to green when rubbed. Its refractive index for red light is 2.63. It is a nonconductor of electricity.

The chemical reactions of melaconite are precisely like those of cuprite, with the exception that the mineral is infusible.

Melaconite is distinguished from the black minerals that contain no copper by its reaction for this metal. It is distinguished from *covellite* and other dark-colored sulphides containing copper by its failure to give the sulphur reaction.

Syntheses.—Crystals of melaconite have been found in the flues of furnaces in which copper compounds and moist NaCl are being treated. They have also been obtained by the decomposition of $CuCl_2$ by water vapor.

Occurrence, Localities and Origin.—The mineral usually occurs associated with other ores of copper, from which it has been formed, in part at least, by decomposition. It is mined with these as an ore. Thin scales are found on the lava of Vesuvius, where it must have been formed by sublimation. Masses occur at the copper mines of Ducktown, Tenn.

Zincite (ZnO)

Zincite is the only oxide of the zinc group of elements known. It is rarely found in crystals. It usually occurs in massive forms associated with other zinc compounds.

Pure zincite is a compound containing 80.3 per cent Zn and 19.7 per cent O. Since, however, the mineral is frequently admixed with manganese compounds it often contains also some manganese and a little iron. A specimen from Sterling Hill, N. J., gave 98.28 per cent ZnO, 6.50 per cent MnO and .44 per cent Fe_2O_3.

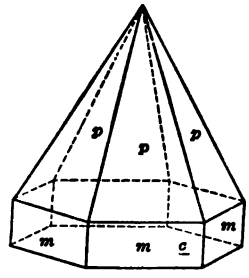


FIG. 64.—Zincite Crystal with ∞P, $10\bar{1}0$ (*m*): P, $10\bar{1}1$ (*p*) and oP, 0001 (*c*).

Natural crystals of zincite are very rare. From a study of artificial crystals it is known that the mineral is hexagonal and hemimorphic (dihexagonal pyramidal class). The principal forms observed are $\infty P(10\bar{1}0)$, $\infty P2(11\bar{2}0)$, oP(0001), $P(10\bar{1}1)$, $P2(11\bar{2}2)$ and various other pyramids of the 1st and 2d orders. Their habit is hemimorphic with P(1011) and oP(0001) at the opposite ends of a short columnar crystal (Fig. 64).

The cleavage of zincite is perfect parallel to oP(0001). Its fracture is conchoidal, its hardness 4–4.5 and density about 5.8. Although colorless varieties are known, the mineral is nearly always deep red or orange-yellow, due most probably to the manganese present in it. The streak of the red varieties is orange-yellow. Its indices of refraction are about 2. The mineral is a conductor of electricity.

When heated in the closed tube the common variety of zincite blackens, but it resumes its original color on cooling. With the borax bead it gives the manganese reaction. Heated on charcoal it coats the coal with a white film, which, when moistened with cobalt solution and heated again with the oxidizing flame of the blowpipe, turns green. The mineral dissolves in acids.

When exposed to the atmosphere zincite undergoes slow decomposition to zinc carbonate.

Syntheses.—Zinc oxide crystals are frequent products of the roasting of zinc ores in ovens. They have also been produced by the action of zinc chloride vapor upon lime and by the action of water upon zinc chloride at a red heat.

Occurrence and Localities.—The mineral occurs only in a few places. It is found with other zinc and manganese minerals near Ogdensburg,

and at Franklin Furnace, in Sussex Co., N. J., in the form of great layers in marble, that are bent into troughs. The layers are probably veins that were filled from below by emanations from a great underground reservoir of igneous rock.

Uses.—Most of the zincite produced in the United States is used in the manufacture of zinc oxide. The ore, which consists of a mixture of zincite, franklinite (see p. 199), and willemite (see p. 306), is crushed and separated into its component parts by mechanical processes. The separated zincite is then mixed with coal and roasted. The zinc oxide is volatilized and is caught in tubes composed of bagging. The willemite and franklinite are smelted to metallic zinc and the residues are used in the manufacture of spiegeleisen.

Production.—Formerly this mineral, together with the silicate found associated with it in New Jersey, constituted the most important source of zinc in this country. At present most of the metal is obtained from sphalerite. Of the 380,000 tons of zinc in spelter and zinc compounds produced in the United States during 1912 about 69,760 tons were made from zincite and the ores associated with it. This had an estimated value of $9,626,991.

THE SESQUIOXIDES

The sesquioxides (R_2O_3) include a few compounds of the nonmetals that are comparatively rare and a group of metallic compounds that includes two minerals of great economic importance. One of these, *hematite* (Fe_2O_3), is the most valuable of the iron ores.

ARSENOLITE—CLAUDETITE GROUP

The only group of the nonmetallic sesquioxides that need be referred to in this place comprises those of arsenic and antimony. This is an isodimorphous group including four minerals.

Isometric		Monoclinic
Arsenolite	As_2O_3	*Claudetite*
Senarmontite	Sb_2O_3	*Valentinite*

All the minerals of the group are comparatively rare. The isometric forms occur in well developed octahedrons and in crusts covering other minerals. They are also found in earthy masses. It is probable that at high temperatures the isometric forms pass over into the monoclinic modifications, as some of the latter have been observed to consist of aggregates of tiny octahedrons. Crystals of claudetite are distinctly

monoclinic, but they are so twinned as to possess an orthorhombic habit. Valentinite crystals, on the contrary, appear to be plainly orthorhombic, but their apparent orthorhombic symmetry may be due to submicroscopic twinning of the same character as that in claudetite, but which in the latter mineral is macroscopic.

All four minerals occur as weathered products of compounds containing As or Sb. They give the usual blowpipe reactions for As or Sb. In the closed tube they melt and sublime.

Arsenolite (As_2O_3) is colorless or white. Its specific gravity is 3.7 and refractive index for sodium light = 1.755. It usually occurs in octahedrons, or in combinations of O(111) and ∞O(110), but these when viewed in polarized light are often seen to be anisotropic. The mineral is found also in aggregates of hair-like crystals with a hardness of 1.2. It is soluble in hot water, yielding a solution with a sweetish taste.

Senarmonite (Sb_2O_3) is gray or white. Its density is 5.2 and $n = 2.087$ for yellow light. Its octahedral crystals are also often anisotropic; its hardness = 2. It is soluble in hot HCl but is only very slightly soluble in water. When heated it turns yellow; but becomes white again upon cooling.

Claudetite (As_2O_3) is monoclinic prismatic, with $a : b : c = .4040 : 1 : .3445$ and $\beta = 86° 03'$. Its white crystals are usually tabular parallel to $\infty P \breve{\infty}$ (010) and are twinned, with $\infty P \bar{\infty}$ (100) the twinning plane. Their cleavage is parallel to $\infty P \breve{\infty}$ (010) and their density is 4.15. H = 2.5. The mineral is an electrical nonconductor.

Valentinite (Sb_2O_3) is apparently orthorhombic bipyramidal (possibly monoclinic prismatic) with $a : b : c = .3914 : 1 : .3367$. Its crystals are tabular or columnar in habit and are very complex. The mineral is found also in radial groups of acicular crystals and in granular and dense masses. Its color is white, pink, gray or brown, and streak white. Its density is 5.77 and hardness 2.5–3. It is insoluble in HCl. It is a nonconductor of electricity.

CORUNDUM GROUP

The sesquioxides of aluminium and iron constitute an isomorphous group crystallizing in the rhombohedral division of the hexagonal system (ditrigonal scalenohedral class). Both the aluminium and iron compounds, *corundum* and *hematite*, are of great economic importance.

Hematite (Fe_2O_3)

Hematite is one of the most important minerals, if not the most important one, from the economic standpoint, since it is the most valuable of all the iron ores. It is known by its dark color and its red powder. It occurs in black, glistening crystals, in yellow, brown or red earthy masses, in granular and micaceous aggregates and in botryoidal and stalactitic forms.

Chemically, the mineral is Fe_2O_3 corresponding to 30 per cent O and 70 per cent Fe. In addition to these constituents, hematite often contains some magnesium and some titanium. By increase in the latter element it passes into a mineral which has not been distinguished from ilmenite (see p. 462).

The habit of hematite crystals is nearly always rhombohedral.

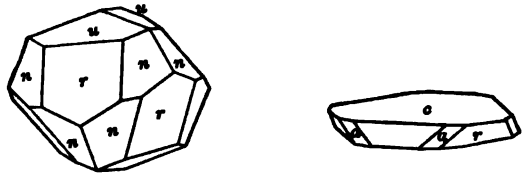


FIG. 65.—Hematite Crystals with R, $10\bar{1}1$ (*r*); $\frac{4}{3}P2$, $22\bar{4}3$ (*n*); $\frac{1}{4}R$ $10\bar{1}4$ (*u*); $\infty P2$, $11\bar{2}0$ (*a*) and oR, 0001 (*c*).

Their axial ratio is $a : c = 1 : 1.3658$, and the predominant forms are $R(10\bar{1}1)$, $\frac{1}{4}R(10\bar{1}4)$, $\frac{4}{3}P2(22\bar{4}3)$, the prisms $\infty P(10\bar{1}0)$ and $\infty P2(11\bar{2}0)$ and often the basal plane (Fig. 65). In addition, about 110 other forms have been identified. The crystals are often tabular, and sometimes are grouped into aggregates resembling rosettes. In many cases the terminal faces are rounded. A parting is often observed parallel to the basal plane, due to the occurrence of the mineral in aggregates in which each crystal is tabular.

Hematite has no well defined cleavage. Its fracture is conchoidal or earthy. Its crystals are black, glistening and opaque, except in very small splinters. These are red and transparent or translucent. Earthy varieties are red. The streak of all varieties is brownish red or cherry-red. The hardness of the crystallized hematite is 5.5–6.5 and its density about 5.2. It is a good conductor of electricity. Its refractive indices are: $\omega = 3.22$, $\epsilon = 2.94$ for yellow light.

The mineral is infusible before the blowpipe. In the reducing flame on charcoal it becomes magnetic, and when heated with soda it is reduced to a magnetic metallic powder. It is soluble in strong hydrochloric acid.

The crystalline and earthy aggregates of hematite to which distinct names have been given are:

Specular, when the aggregate consists of grains with a glistening, metallic luster, like the luster of the crystals. When the grains are thin tabular the aggregate is said to be micaceous.

Columnar or fibrous, when in fibrous masses. The color is usually brownish red and the luster dull. The botryoidal, stalactic and various imitative forms belong here. *Red hematite* is a compact red variety in which the fibrous structure is not very pronounced.

Red ocher is a red earthy hematite mixed with more or less clay and other impurities.

Clay ironstone is a hard brownish or reddish variety with a dull luster. It is usually a mixture of hematite with sand or clay.

Oölitic ore is a red variety composed of compacted spherical or nearly spherical grains that have a concentric structure.

Fossil ore differs from oölitic ore mainly in the fact that there are present in it small shells and fragments of shells that are now composed entirely of hematite.

Martite is a pseudomorph of hematite after magnetite.

Hematite is distinguished from all other minerals by its red powder and its magnetism after roasting.

Syntheses.—Crystals of hematite are obtained by the action of steam on ferric chloride at red heat; by heating ferric hydroxide with water containing a trace of NH_4F to 250° in a closed tube, and by cooling a solution of Fe_2O_3 in molten borax or halite.

Occurrence and Origin.—Hematite is found in beds with rocks of nearly all ages. It occurs also as a deposit on the bottoms of marshy ponds, and in small grains in the rocks around volcanic vents. The crystallized variety is often deposited on the sides of clefts in rocks near volcanoes and on the sides of certain veins. It is produced by sublimation, by sedimentation and by metasomatic processes.

Localities.—Handsome crystals occur on the island of Elba; near Limoges in France; in and on the lavas of Vesuvius and Etna; at many places in Switzerland, Sweden, etc., and at many in the United States.

Beds of great economic importance occur in the Gogebic, Menominee and Marquette districts in Michigan; in the Mesabe and Vermilion districts in Minnesota; in the Pilot Knob and Iron Mountain districts in Missouri, and in the southern Appalachians, especially in Alabama.

Uses.—In addition to its use as an ore the fibrous variety of hematite is sometimes cut into balls and cubes to be worn as jewelry. The earthy varieties are ground and employed in the manufacture of a dark red

paint such as is used on freight cars, and the powder of some of the massive forms is used as a polishing powder.

Production.—Most of the iron ore produced in the United States is hematite, and by far the greater proportion of it comes from the Lake Superior region. The statistics for 1912 follow:

QUANTITY (IN LONG TONS) OF IRON ORE MINED IN THE SEVERAL LEADING STATES DURING 1912

	Hematite	Other Iron Ores	Total
Minnesota	34,431,000	.....	34,431,000
Michigan	11,191,000	.....	11,191,000
Alabama	3,814,000	749,000	4,563,000
New York	106,327	1,110,000	1,216,327
Wisconsin	860,000	.....	860,000
Tennessee	246,000	171,000	417,000
Total in U. S.	51,345,782	3,804,365	55,150,147

The total production in 1912 was valued at about $104,000,000.

Corundum (Al_2O_3)

Corundum is the hardest mineral known, with the exception of diamond. In consequence of its great hardness an impure variety is used as an abrading agent under the name of *emery*. It is also one of the most valuable of the gem minerals. It occurs as crystals and in granular masses.

The mineral is nearly always a practically pure oxide of aluminium of the composition Al_2O_3, in which there are 52.9 per cent Al and 47.1 per cent O. The impure varieties usually contain some iron, mainly as an admixture in the form of magnetite.

The axial ratio of corundum crystals is 1 : 1.36. The forms are usually simple pyramids, among which $\frac{4}{3}P2(22\bar{4}3)$ and $\frac{8}{3}P2(44\bar{8}3)$ are the most common (Fig. 66), and the prism $\infty P2(11\bar{2}0)$. The basal plane is also common (Fig. 67). Many crystals consist of a series of steep prisms and the basal plane, with a habit that may be described as barrel-shaped (Fig. 68). The crystals are often rough with rounded edges. The prismatic and pyramidal faces are usually striated horizontally, and the basal plane by lines radiating from the center.

All corundum crystals are characterized by a parting parallel to the basal plane, and often by a cleavage parallel to the rhombohedron, due to the presence of lamellae twinned parallel to $R(10\bar{1}1)$. The fracture of the mineral is conchoidal or uneven. Its density is about 4 and its

hardness 9. The mineral possesses a vitreous to adamantine luster. It is transparent or translucent. Its streak is uncolored. Its color varies from white, through gray to various shades of red, yellow, or blue. The blue varieties are pleochroic in blue and greenish blue shades. The mineral is a nonconductor of electricity. Its refractive indices for yellow light are: $\omega = 1.7690$, $\epsilon = 1.7598$.

Three varieties of corundum are recognized in the arts: Sapphire, corundum and emery.

Sapphire is the generic name for the finely colored, transparent or translucent varieties that are used as gems, watch jewels, meter bearings, etc. The sapphires are divided by the jewelers into sapphires, possessing

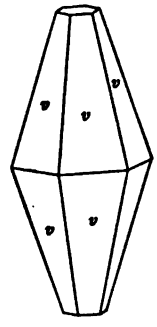


FIG. 66.

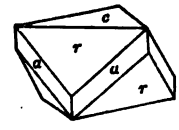


FIG. 67.

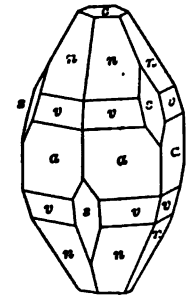


FIG. 68.

FIG. 66.—Corundum Crystal with $\frac{8}{3}P2$, $44\bar{8}3$ (v).

FIG. 67.—Corundum Crystal with R, $10\bar{1}1$ (r); $\infty P2$, $11\bar{2}0$ (a), and oR, 0001 (c).

FIG. 68.—Corundum Crystal. Form a, v and c as in previous figures. Also $\frac{4}{3}P2$, $22\bar{4}3$ (n) and $-2R$, $02\bar{2}1$ (s).

a blue color, rubies, possessing a red shade, Oriental topazes, Oriental emeralds and Oriental amethysts having respectively yellow, green and purple tints.

Corundum is the name given to dull colored varieties that are ground and used as polishing and cutting materials.

Emery is an impure granular corundum, or a mixture of corundum with magnetite (Fe_3O_4) and other dark colored minerals. Emery, like corundum, is used as an abrasive. It is less valuable than corundum powder because it contains a large proportion of comparatively soft material.

Powdered corundum when heated for a long time with a few drops of cobalt nitrate solution assumes a blue color. The mineral gives no definite reaction with the beads It is infusible and insoluble. It is

most easily recognized by its hardness. The mineral alters to spinel (p. 196) and to fibrous and platy aluminous silicates.

Syntheses.—Corundum crystals have been produced artificially in many different ways, but only recently has the manufacture of the gem variety been accomplished on a commercial scale. Amorphous Al_2O_3 dissolves in melted sodium sulphide and crystallizes from the glowing mass at a red heat. By melting Al_2O_3 in a mass of some fluoride and potassium carbonate containing a little chromium, and using comparatively large quantities of material, violet and blue rubies were obtained by Fremy and Verneuil. Rubies are also produced by melting Al_2O_3 and a little Cr_2O_3 for several minutes at a temperature of 2250° C. in an electric oven.

In recent years reconstructed rubies have become a recognized article of commerce. These are crystalline drops of ruby material made by melting tiny splinters and crystals of the mineral in an electric arc.

Alundum is an artificial corundum made by subjecting the aluminium hydroxide, bauxite, to an intense heat (5000°–6000°) in an electric furnace.

Occurrence and Origin.—Corundum usually occupies veins in crystalline rocks or is embedded in basic intrusive rocks and in granular limestone. The sapphire varieties are also often found as partially rounded crystals in the sands of brook beds. The varieties found in igneous rocks are primary crystallizations from the magmas producing the rocks. The varieties in limestones are the result of metamorphic processes.

Localities.—Sapphires are obtained mainly from the limestone of Upper Burma. They are known also to occur in Afghanistan, in Kashmir and in Ceylon. They are occasionally found in the diamond-bearing gravels of New South Wales and in the bed of the Missouri River, near Helena, Montana. In the United States sapphire is mined near the Judith River in Fergus Co., and in Rock Creek in Granite Co., Mont., where it occurs in a dike of the dark igneous rock known as monchiquite, and is washed from the placers of three streams in the same State. The only southern mines that have produced gem material are at Franklin and Culsagee, N. C., and from these not any great quantity of stones of gem quality have been taken.

The largest sapphire crystal ever found was taken, however, from one of them. It weighs 312 lb., is blue, but opaque. From one of these mines, also, came the finest specimen of green sapphire (Oriental emerald) ever found.

Corundum in commercial quantities occurs on the coast of Malabar,

in Siam, near Canton, China, and in southeastern Ontario, Canada. Emery is obtained from several of the Grecian Islands, more particularly Naxos, and from Asia Minor. It is mined in the United States at Chester, Mass., and at Peekskill, N. Y. Crystallized corundum occurs near Litchfield, Conn.; at Greenwood, Maine; at Warwick and Amity, N. Y.; at Mineral Hill, Penn.; in Patrick Co., Va.; at Corundum Hill and at Laurel Creek, Macon Co., N. C., and at various points in Georgia, at all of which places it has been mined. In all the localities within the United States the corundum occurs on the peripheries of masses of peridotite (olivine rocks).

Uses.—Corundum, emery and alundum, after crushing and washing, are used as abrasives and in the manufacture of cutting wheels.

Production.—The amount of sapphire produced in the United States in 1912 was valued at $195,505. Most of it was used for mechanical purposes, but 384,000 carats were used as gem material.

Most of the corundum used in the United States is imported from Canada, where it occurs in Haliburton, Renfrew and neighboring counties in Ontario, as crystals scattered through the coarse-grained crystalline rocks known as syenite, nepheline syenite and anorthosite.

Most of the emery is also imported. Only 992 tons with a value of $6,652 were mined in 1912. The imports of corundum and emery were valued at $501,725, but the importation of these substances is gradually diminishing because of the rapid increase in the amounts of alundum and carborundum manufactured. In 1912 the production of alundum reached 13,300,000 lb. valued at $796,000.

THE DIOXIDES

THE NONMETALLIC DIOXIDES

There are but few dioxides of the nonmetals that occur as minerals, and only one of these, *quartz*, is abundant.

SILICA GROUP

Silica (SiO_2) occurs in nature in four or five important modifications as follows:

α *Quartz*, trigonal-trapezohedral class, below 575°.

β *Quartz*, hexagonal-trapezohedral class, above 575° and below 870°.

Tridymite, rhombic bipyramidal, pseudohexagonal habit. Hexagonal above 117°.

Cristobalite, tetragonal system, pseudocubic habit. Isometric above 140°.

Chalcedony is regarded by many mineralogists as a form of quartz, but its index of refraction for red light is $n = 1.537$, which is noticeably lower than that of either ray in quartz, which is $\omega = 1.5390$, $\epsilon = 1.5480$ for the same color. Its hardness also is a little less than that of quartz. Some mineralogists believe that all of these properties may be explained on the assumption that the mineral is a mass of fine quartz fibers, perhaps mixed with other substances, but those who have investigated it by high temperature methods are inclined to regard it as a distinct mineral.

Quartz (SiO_2)

Quartz vies with calcite for the commanding position among the minerals. It is very abundant, and appears under a great variety of

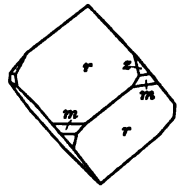


FIG. 69.

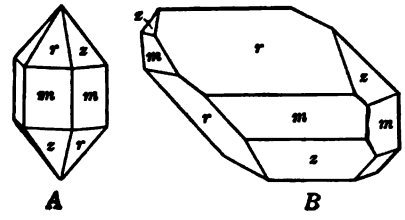


FIG. 70.

FIG. 69.—Quartz Crystal Exhibiting Rhombohedral Symmetry. R, $10\bar{1}1$ (r); $-$R, $01\bar{1}1$ (z) and ∞R, $10\bar{1}0$ (m).

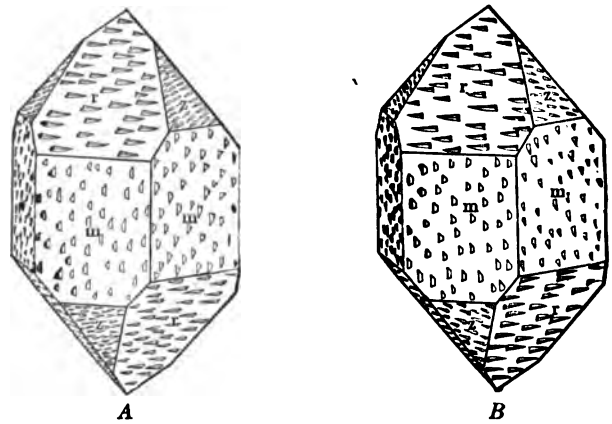
FIG. 70.—Ideal (A) and Distorted (B) Quartz Crystals Bounded by same Forms as in Fig. 69.

forms. Often it occurs in distinct crystals. At other times it appears as grains without distinct crystal forms, and again it constitutes great massive deposits.

Pure quartz consists of 46.7 per cent Si and 53.3 per cent O. Massive varieties often contain, in addition, some opal ($Si(OH)_4$), and traces of iron, calcite ($CaCO_3$), clay, and other impurities.

The crystallization of quartz is in the trapezohedral tetartohedral division of the hexagonal system (trigonal-trapezohedral class), at temperatures below 575°. When formed above this temperature its symmetry is hexagonal trapezohedral (hemihedral). The former is known as α quartz, and the latter as β quartz. They readily pass one into the other at the stated temperature. The axial ratio is 1 : 1.1. The principal forms observed are $+R(10\bar{1}1)$, $-R(01\bar{1}1)$, $\infty R(10\bar{1}0)$, $\frac{2P_2}{2}(11\bar{2}1)$,

$\frac{6P\frac{6}{5}}{4}(51\bar{6}1)$ (Fig. 74) and a series of steep rhombohedrons and trapezohedrons. Although these may all be tetartohedral, since the geometrical



A B

FIG. 71.—Etch Figures on Two Quartz Crystals of the Same Form, Illustrating Differences in Symmetry. A. Right-Hand Crystal. B. Left-Hand Crystal. (*After Penfield.*)

FIG. 72.—Group of Quartz Crystals with Distorted Rhombohedral Faces. (*Foote Mineral Company.*)

forms of the first four are not distinguishable from the corresponding hemihedral ones, the crystals possess a rhombohedral symmetry (Fig. 69). The angle $10\bar{1}1 \wedge \bar{1}101 = 85° 46'$.

Often the +R and the −R faces are equally developed so that they appear to belong to the hexagonal pyramid P (Fig. 70A). Their true character, however, is clearly brought out by etching, when figures are produced on the +R and the −R that are differently situated with respect to the edges of the faces (Fig. 71). On the other hand, on many crystals some of the R faces are very much enlarged at the expense of the others (Fig. 72).

The crystals are commonly prismatic. Often they are so dis-

FIG. 73.

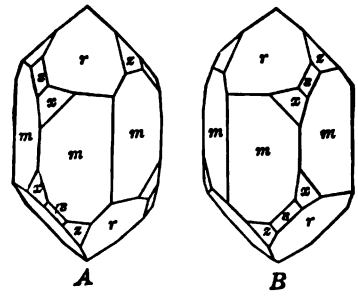


FIG. 74.

FIG. 73.—Tapering Quartz Crystal with Rhombohedral Symmetry. A. Combination of *r*, *z*, *m* and Two Steep Rhombohedrons. B. Cross-section near Top.

FIG. 74.—Quartz Crystals Containing ∞R, $10\bar{1}0$ (*m*); R, $10\bar{1}1$ (*r*); −R, $01\bar{1}1$ (*z*); and $\frac{2P2}{2}l$, $2\bar{1}11$ (*s*); $\frac{6P\frac{6}{5}}{2}l$, $5\bar{1}\bar{6}1$ (*x*) on A; and $\frac{2P2}{2}r$, $11\bar{2}1$ (*s*); $\frac{6P\frac{6}{5}}{2}r$, $51\bar{6}1$ (*x*) on B.

torted that it is difficult to detect the position of the *c* axis (Fig. 70B). The striations on ∞R($10\bar{1}0$) are, however, always parallel to the edges between R and ∞R. When these are sharply marked the position of the vertical axis is easily recognized. Many crystals taper sharply toward the ends of the *c* axis. This tapering is due to oscillatory combination of the prism ∞R with rhombohedrons (Fig. 73).

The habits of the crystals vary with the crystallization of the quartz. On crystals of the β phase the +R and −R faces are equally developed and trigonal trapezohedrons are absent. The crystals are hexagonal in

habit. Crystals of the α phase usually exhibit marked differences in the size and character of the rhombohedral planes; and trigonal trapezohedrons may be present on them. Such crystals are usually trigonal in habit and prismatic.

The small $\frac{2P2}{2}(11\bar{2}1)$ faces on all types of crystals (Fig. 74) are always striated parallel to the edge between this plane and +R. By their aid the +R can always be distinguished from the −R. This is a matter of some practical importance since plates cut from quartz crystals possess the power of rotating a ray of polarized light. The plates cut

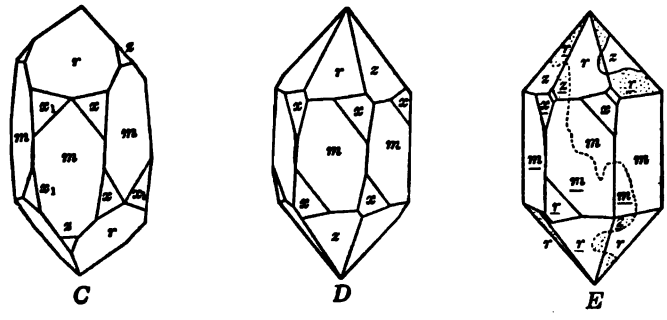


FIG. 75.—Supplementary Twins of Quartz.

C is a combination of A and B in Fig. 74 twinned about $\infty P2(11\bar{2}0)$. This is known as the Brazil law.

D is a combination of two crystals like B twinned about *c* as the twinning axis. One is revolved 60° with reference to the others, thus causing the *r* and *z* faces to fall together. Swiss law. E is a twin like D, showing portions of planes belonging to each individual. It contains also the form *s*.

from some crystals turn the ray to the right; those cut from others turn it to the left. Crystals that produce plates of the first kind are known as right-handed crystals; those that produce plates of the second kind as left-handed crystals. Since this property of quartz plates is employed in the construction of optical instruments for use in the detection of sugars and certain other substances in solution it is important to be able to distinguish those crystals that will yield right-handed plates from those that will yield left-handed ones. Observation has shown that when the $\frac{2P2}{2}(11\bar{2}1)$ faces are in the upper right-hand corner of the ∞ R plane immediately beneath +R the crystal is right-handed. When these faces are in the upper left-hand corner of this ∞ R plane the crystal

is left-handed. In either case, when $\frac{6P\frac{6}{5}}{4}(51\bar{6}1)$ is present it occurs between $\frac{2P2}{2}$ $(11\bar{2}1)$ and the ∞ R face beneath +R.

Interpenetration twins of quartz are so common that few crystals can be observed that do not exhibit some evidence of twinning (Fig. 75). The twinning plane is ∞ R, so that the *c* axes in the twinned individuals are parallel and, indeed, often coincident. The R faces and the ∞ R faces practically coincide in the twinned parts so that the crystals resemble untwinned ones. The twinning is exhibited by dull areas of −R on bright areas of +R faces and by breaks in the continuity of the striations on ∞ R.

Other twinning laws have also been observed in quartz, but their discussion as well as the more complete discussion of the mineral's crystallization must be left for larger treatises. In the most common of these other laws the individuals are twinned about $P2(11\bar{2}2)$. See Fig. 76.

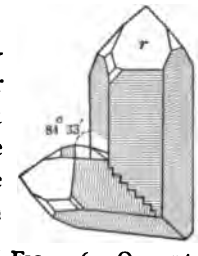


FIG. 76.—Quartz Twinned about $P2(11\bar{2}2)$.

The fracture of quartz is conchoidal. Its hardness is 7 and density 2.65. Its luster is vitreous, or sometimes greasy. Pure specimens are transparent or colorless, but most varieties are colored by the addition of pigments or impurities. When the coloring matter is opaque it may be present in sufficient quantity to render the mineral also opaque. The streak is colorless in pure varieties, and of some pale shade in colored varieties. The mineral is pyroelectric and circularly polarizing as described above. It is an electric insulator at ordinary temperatures. Its refractive indices for yellow light are: $\omega = 1.5443$, $\epsilon = 1.5534$.

Quartz resists most of the chemical agents except the alkalies. It dissolves in fused sodium carbonate and in solutions of the caustic alkalies. It is also soluble in HF and to a very slight degree in water, especially in water containing small quantities of certain salts. When heated to 575° the α variety passes into the β variety; at 870° both varieties pass into tridymite, and at 1470° the tridymite passes over into cristobalite. Gradual fusion occurs just below 1470°.

The varieties of quartz have received many different names depending largely upon their color and the uses to which they are put. They may be grouped for convenience into crystallized and crystalline varieties.

The principal crystallized varieties are:

Rock crystal, the colorless, transparent variety, that often forms distinct crystals. This is the variety that is used in optical instruments. It includes the Lake George diamonds, rhinestones and Brazilian pebbles.

Amethyst, the violet-colored transparent variety.

Rose quartz, the rose-colored transparent variety.

Citrine or *false topaz*, a yellow and pellucid kind.

Smoky quartz or *Cairngorm stone*, a smoky yellow or smoky brown variety that is often transparent or translucent, but sometimes almost opaque.

The last four varieties are used as gems, the Cairngorm stone being a popular stone for mourning jewelry.

Milky quartz is the white, translucent or opaque variety such as so commonly forms the gangue in mineral veins and the material of " quartz veins."

Sagenite is rock crystal including acicular crystals of rutile (TiO_2).

Aventurine is rock crystal spangled with scales of some micaceous mineral.

The principal crystalline varieties are:

Chalcedony, a very finely fibrous, transparent or translucent waxy-looking quartz that forms mamillary or botryoidal masses. Its color is white, gray, blue or some other delicate shade. The water that is always present in it is believed to be held between the minute fibers, and not to be combined with the silica (see also p. 159).

Carnelian is the name given to a clear red or brown chalcedony.

Chrysoprase is an apple-green chalcedony.

Prase is a dull leek-green variety that is translucent.

Plasma differs from prase in having a brighter green color and in being translucent.

Heliotrope, or *bloodstone*, is a plasma dotted with red spots of jasper.

All of the colored chalcedonies are used as gems or as ornamental stones.

Agate is a chalcedony, or a mixture of quartz and chalcedony, variegated in color. The commonest agates have the colors arranged in bands, but there are others, like " fortification agate " in which the colors are irregularly distributed, and still others in which the variation in color is due to visible inclusions, as in " moss-agates." The different bands in banded agates often differ in porosity. This property is taken advantage of to intensify the contrast in their colors. The agate is soaked in oil, or in some other substance, and is then treated with chemicals that act upon the material absorbed by it. Those bands which

have absorbed the greater quantity of this material become darker in color than those that have absorbed less.

Onyx is a very evenly banded agate in which there is a marked contrast in colors. Cameos are onyxes in one band of which figures are cut, leaving another band to form a background.

Sardonyx is an onyx in which some of the bands consist of carnelian. It is usually red and white.

Flint, jasper, hornstone and *touchstone* are very fine grained crystalline aggregates of gray, red or nearly black mixture of opal, chalcedony and quartz. They are more properly rocks than minerals. *Chert* is an impure flint.

Sandstone is a rock composed of sand grains, most of which are quartz, cemented by clay, calcite or some other substance. When the cement is quartz the rock is a *quartzite*. *Oilstones, honestones* and some *whetstones* are cryptocrystalline aggregates of quartz, very dense and homogeneous, except for tiny rhombohedral cavities that are thought to have resulted from the solution of crystals of calcite. They are generally believed to be beds of metamorphosed chert.

Syntheses.—Crystallized quartz has been made in a number of ways both from superheated aqueous solutions and from molten magmas. Crystals have been produced by the action of water containing ammonium fluoride upon powdered glass and upon amorphous SiO_2, and by heating water in a closed glass tube to high temperatures. The separation of crystals from molten magmas is facilitated by the addition of small quantities of a fluoride or of tungsten compounds.

Occurrence and Origin.—Quartz occurs as an essential constituent of many crystalline rocks such as granite, gneiss, etc., and as the almost sole component of certain sandstones. It constitutes the greater portion of most sands and the material of many veins. It also occurs as pseudomorphs after shells and other organic bodies embedded in rocks, having replaced the original substance of which these bodies were composed. It is also one of the decomposition products of many silicates. It may thus be primary or secondary in origin. It may result from igneous or aqueous processes, or it may be a sublimation product.

Localities.—Quartz is so widely spread in its distribution that only a very few of its most interesting localities can be referred to in this place.

The finest specimens of rock crystals come from Dauphiné, France; Carrara, in Tuscany; the Piedmont district, in Italy; and in the United States from Middleville, and Little Falls, N. Y.; the Hot Springs, Ark., and from several places in Alexander Co., N. C. Smoky quartz is found in good crystals in Scotland; at Paris, Me.; in Alexander

Co., N. C., and in the Pike's Peak region of Colorado. The handsomest amethysts come from Ceylon, Persia, Brazil, Nova Scotia and the country around Lake Superior. Rose quartz occurs in large quantity at Hebron, Paris, Albany and Georgetown, Me.

Fine agates and carnelians are brought from Arabia, India and Brazil. They are abundant in the gravels of Agate Bay and of other bays and coves on the north shore of Lake Superior.

Chalcedony is abundant in the rocks of Iceland and the Faroe Islands, in those on the northwest side of Lake Superior, and in the gravels of the Columbia, the Mississippi and other western rivers.

The other valuable varieties of the mineral occur largely in the Far East.

Agatized, or silicified, wood of great beauty exists in enormous quantity in an old petrified forest near Corrizo, Ariz. It is also found in the Yellowstone Park; near Florissant, Colo., and in other places in the Far West. This wood has had all of its organic matter replaced molecule for molecule by quartz in such a manner that its original structure has been perfectly preserved.

Uses.—Rock crystal is used more or less extensively in the construction of optical instruments and in the manufacture of cheap jewelry. Smoky quartz, amethyst, onyx, carnelian and heliotrope stones are used as gems, and agate, prase, chrysoprase and rose quartz as ornamental stones.

Milky quartz, ground to coarse powder, is employed in the manufacture of sandpaper. Its most extensive use, however, is in the manufacture of glass and pottery. Earthenware, porcelain and some other varieties of potter's ware are vitrified mixtures of clay and ground quartz, technically known as "flint." Ordinary glass is a silicate of calcium or lead and the alkalies, sodium or potash. It is made by melting together soda, potash, lime or lead oxide and ground quartz or quartz sand, and coloring with some metallic salt. A pure quartz glass is now being made for chemical uses by melting pure quartz sand.

Quartz is sometimes used as a flux in smelting operations. In the form of sandstone, it is used as a building stone, and in the form of sand it is employed in various building operations. Bricks cut from dense quartzites (very hard and compact sandstones) are often employed for lining furnaces.

The uses of honestones, oilstones, and whetstones are indicated by their names.

Production.—Many varieties of quartz are produced in the United States to serve various uses. Vein quartz is crushed and employed

in the manufacture of wood filler, paints, pottery, scouring soaps, sandpaper and abrasives. It is also used in making ferro-silicon, chemical ware, pottery, sand-lime brick, quartz glass, etc. The total quantity produced for these purposes in 1912 was 97,874 tons, valued at $191,685.

The largest quantity of quartz produced is in the form of sand, of which 38,600,000 tons were marketed in 1912 at a valuation of $15,300,000. Sandstone, valued at $6,900,000, was quarried for building and paving purposes. Oilstones, grindstones, millstones, etc., which are made from special varieties of sandstone, were produced to the value of $1,220,000.

Gem quartz obtained in 1912 was valued at about $22,000. This comprised petrified wood, chrysoprase, agate, amethyst, rock crystal, smoky quartz, rose quartz, and gold quartz (white quartz containing particles of gold).

THE METALLIC DIOXIDES

The metallic dioxides include the oxides of tin, titanium, manganese and lead. Of these the manganese dioxide may be dimorphous, and the titanium dioxide is trimorphous. A dioxide of zirconium is also known, *baddeleyite*, but it is extremely rare. The mineral *zircon* ($ZrSiO_4$) is often regarded as being isomorphous with *cassiterite* (SnO_2) and *rutile* (TiO_2) because of the similarity in the crystallization of the three minerals. The three, therefore, are placed in the same group, in which case all must be regarded as salts of metallic acids, thus: $TiO_2 = TiTiO_4$, $SnO_2 = SnSnO_4$, zircon $= ZrSiO_4$. Other authorities regard zircon as an isomorphous mixture of TiO_2 and SiO_2. In this book zircon is placed with the silicates and the other minerals are considered as oxides.

The two manganese dioxides are *polianite* and *pyrolusite*. The former is tetragonal and the latter orthorhombic. It is possible, however, that the crystals of pyrolusite are pseudomorphs and that the substance is a mixture of polianite and some hydroxide, as it nearly always contains about 2 per cent H_2O.

The three titanium oxides are *rutile*, which is tetragonal; *brookite*, which is orthorhombic, and *anatase* or *octahedrite*, which is tetragonal. Although rutile and anatase crystallize in the same system, their axial ratios are different, as are also their crystal habits and their physical properties. A few of these differences are indicated below:

Rutile	$a : c = 1 : .6439$;	Sp. Gr. $= 4.283$;	$\omega_{na} = 2.6158$;	$\epsilon_{na} = 2.9029$.
Anatase	$= 1 : 1.7771$;	Sp. Gr. $= 3.9$;	$\omega_{na} = 2.5618$;	$\epsilon_{na} = 2.4886$.

Of the three modifications of titanium dioxide, anatase may be made at a comparatively low temperature. Brookite requires a higher temperature for its production, but rutile is producible at both high and low temperatures. Under the conditions of nature both brookite and anatase pass readily into rutile.

Of the seven dioxides discussed, four are members of a single group.

RUTILE GROUP

The rutile group consists of four minerals apparently completely isomorphous, though no mixed crystals of any two have been discovered.[1] All crystallize in the tetragonal system (ditetragonal bipyramidal class), with the same forms and with closely corresponding axial ratios. The names of the members of the group and their axial ratios follow:

Cassiterite	(SnO_2)	$a : c = 1 : .6726$
Rutile	(TiO_2)	$= 1 : .6439$
Polianite	(MnO_2)	$= 1 : .6647$
Plattnerite	(PbO_2)	$= 1 : .6764$

Cassiterite (SnO_2)

Cassiterite, or tinstone, is the only worked ore of tin. It occurs as rolled pebbles of a dark brown color in the beds of streams, as fibrous aggregates, and as glistening black crystals associated with other minerals in veins.

The analyses of cassiterite indicate it to be essentially an oxide of tin, or, possibly, a stanyl stannate ($(SnO)SnO_3$), with the composition, $Sn = 78.6$ per cent; $O = 21.4$ per cent. The mineral nearly always contains some iron oxide and often oxides of tantalum, of zinc or of arsenic. The presence of iron and tantalum is so general that most crystals of cassiterite may be regarded as isomorphous mixtures of $(SnO)(SnO_3)$, $Fe(SnO_3)$ and $Fe(TaO_3)_2$. Thus, a crystal from the Etta Mine in the Black Hills, S. D., gave $SnO_2 = 94.36$; $FeO = 1.62$; $Ta_2O_5 = 2.42$ and $SiO_2 = 1.00$, indicating a mixture of 5 pts. of $Fe(TaO_3)_2$, 18 pts. of $Fe(SnO_3)$ and 303.5 pts. of $(SnO)(SnO_3)$.

The crystals of cassiterite have an axial ratio of $1 : .6726$. They are usually short prisms in habit. They often consist of the simple combination P(111) and P∞(101) (Fig. 77), or of these forms, together with $3P\frac{3}{2}(321)$ and various prisms (Fig. 78). Twins are common, the

[1] An isomorphous mixture of the rutile and cassiterite molecules has recently been described from Greifenstein, Austria, but its existence has not yet been confirmed.

twinning plane being P∞ (101). When the individuals twinned have small prismatic faces the resulting combination is often called a visor twin (Fig. 79), because of its supposed resemblance to the visor of a helmet. By repetition of the twinning very complex groupings are produced. The angle 111 ∧ 1$\bar{1}$1 = 58° 19′.

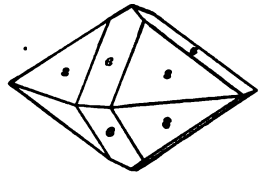


FIG. 77.

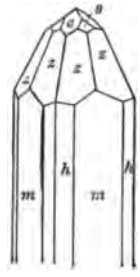


FIG. 78.

FIG. 77.—Cassiterite Crystal with P, 111 (*s*) and P∞, 101 (*e*).
FIG. 78.—Cassiterite Crystal with *s*, *e* and ∞P, 110 (*m*); ∞P2, 210 (*h*); 3P$\frac{3}{2}$, 321 (*z*).

The cleavage of cassiterite is imperfect parallel to ∞P∞ (100) and P(111). Its fracture is uneven. The color of the massive mineral is some dark shade of brown by reflected light, and of the crystals black. By transmitted light, the mineral is brown or black. Its luster is very brilliant, and its streak is white, gray or brown. The purest specimens

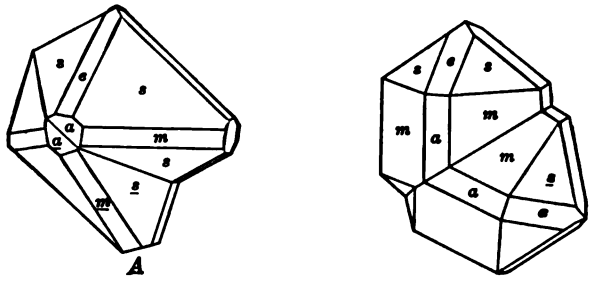


FIG. 79.—Cassiterite Twinned about P∞ (101). *a* = ∞P∞, 100. A = Visor Twin.

are nearly transparent, though the ordinary varieties are opaque. Their hardness is about 6.5 and density about 7. The mineral is a nonconductor of electricity. Its refractive indices for yellow light are: $\omega = 1.9965$, $\epsilon = 2.0931$.

Three varieties of cassiterite are recognized, distinguished by physical characteristics. The ordinary variety known as *tinstone* is crystallized

or massive. *Wood tin* is a botryoidal or reniform variety, concentric in structure and composed of radiating fibers. The third variety is *stream tin*. This consists of water-worn pebbles found in the beds of streams that flow over cassiterite-bearing rocks.

Cassiterite is only slightly acted upon by acids. It may be reduced to a metallic globule of tin only with difficulty, even when mixed with sodium carbonate and heated intensely on charcoal. With borax it yields slight reactions for iron, manganese or other impurities. When placed in dilute hydrochloric acid with pieces of granulated zinc, fragments of cassiterite become covered with a dull gray coating of metallic tin which can be burnished by rubbing with a cloth or the hand. When rubbed by the hand the odor of tin in contact with flesh is easily detected.

The mineral is most easily distinguished from other compounds that resemble it in appearance by its high density and its inertness when treated with reagents or before the blowpipe.

Syntheses.—Crystals of cassiterite have been obtained by passing steam and vapor of tin chloride or tin fluoride through red-hot porcelain tubes, and by the action of tin chloride vapor upon lime.

Occurrence and Origin.—Tinstone is found as a primary mineral in coarse granite veins with topaz, tourmaline, fluorite, apatite and a great number of other minerals. It also occurs impregnating rocks, sometimes replacing the minerals of which they originally consisted. In these cases it is the product of pneumatolytic processes. In many places it constitutes a large proportion of the gravel in the beds of streams.

Localities and Production.—The crystallized mineral occurs at many places in Bohemia and in Saxony, at Limoges in France and sparingly in a few places in the United States, especially near El Paso, Texas, in Cherokee Co., N. C., in Lincoln Co., S. C., and near Hill City, S. D. Massive tinstone and stream tin occur in large enough quantities to be mined in Cornwall, England; on the Malay Peninsula and on the islands lying off its extremity; in Tasmania; in New South Wales, Victoria and Queensland, Australia; in the gold regions of Bolivia; at Durango in Mexico, and at various points in Alaska, at some of which there are 400 lb. of cassiterite in a cubic yard of gravel.

The principal tin ore-producing regions of the world are the Straits district, including the Malay Peninsula and the islands of the Malay Archipelago; Australia; Cornwall, England; the Dutch East Indies, and Bolivia. Of the total output of 122,752 tons of tin produced in 1911, 61,712 tons were made from the Straits ore, 25,312 tons from the ore produced in Bolivia and 16,800 tons from Banka ore. Of the total

quantity of tin produced about 78 per cent is said to come from stream tin and 22 per cent from ore obtained from veins. The quantity obtained from ore mined in the United States in 1911 included 61 tons from Alaskan stream tin and two tons from the tinstone mined in the Franklin Mountains near El Paso, Texas. Mines have been opened in San Bernardino Co., California, and in the Black Hills, South Dakota, but they have not proved successful. The mines at El Paso, Texas, are not yet fully developed, although they promise to be profitable in the near future. The crystals are scattered through quartz veins and through a pink granite near the contacts with the veins. The average composition of the ore is 2 per cent. This is concentrated to a 60 per cent ore before being smelted. The production during 1912 was 130 tons of stream tin from Buck Creek, Alaska. This was valued at $124,800. In the following year 3 tons of cassiterite were shipped from Gaffney, S. C. The imports of tin into the United States during 1911 were 53,527 tons valued at more than $43,300,000.

Extraction.—The tin is extracted from the concentrated ore by the simple process of reduction. Alternate layers of the ore and charcoal are heated together in a furnace, when the metal results. This collects in the bottom of the furnace and is ladled or run out. The crude metal is refined by remelting in special refining furnaces.

Uses of the Metal.—The metal tin is employed principally for coating other metals, either to prevent rusting or to prevent the action upon them of chemical reagents. Tin plate is thin sheet iron covered with tin. Copper for culinary purposes is also often covered with this metal. It is used also extensively in forming alloys with copper, antimony, bismuth and lead. Among the most important of these alloys are bronze, bell metal, babbitt metal, gun metal, britannia, pewter and soft solder. Its alloy, or amalgam, with mercury is used in coating mirrors. Several of its compounds also find uses in the arts. Tin oxide is an important constituent of certain enamels. The chlorides are used extensively in dyeing calicoes, and the bisulphide constitutes "bronze powder" or "mosaic gold," a powder employed for bronzing plaster, wood and metals.

Rutile (TiO_2)

Rutile is one of the oxides of the comparatively rare element titanium. It occurs commonly in dark brown opaque cleavable masses and in brilliant black crystals.

Pure rutile consists of 40 per cent O and 60 per cent Ti. Nearly all specimens, however, contain in addition some iron, occasionally as much

as 9 per cent or 10 per cent, which is probably due to the admixture of Fe_2O_3 and $FeTiO_3$ in solid solution.

Rutile is perfectly isomorphous with cassiterite. Its axial ratio is 1 : .6439. The principal planes observed on its crystals are practically the same as those observed on cassiterite (Fig. 80). Twins are common, with P ∞ (101) the twinning plane. (Fig. 81.) This twinning is often repeated, producing elbow-shaped groups (Fig. 82), or by further repe-

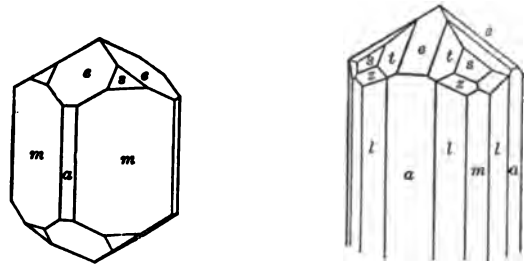


FIG. 80.—Rutile Crystals with ∞ P, 110 (*m*); ∞ P ∞, 100 (*a*); P ∞, 101 (*e*); P, 111 (*s*); ∞ P3, 310 (*l*); P3, 313 (*t*) and 3P$\frac{3}{2}$, 321 (*z*).

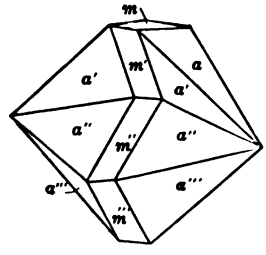


FIG. 81.

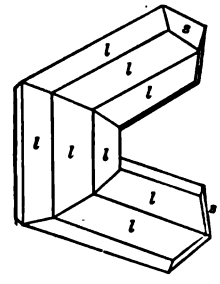


FIG. 82.

FIG. 81.—Rutile Eightling Twinned about P ∞ (101).
FIG. 82.—Rutile Twinned about P ∞ (101). Elbow Twin.

tition wheel-shaped aggregates (Fig. 83). In another common law the twinning plane is 3P ∞ (301) (Fig. 84). The angle $111 \wedge 1\bar{1}1 = 56° \; 52\frac{1}{2}'$. The crystals are prismatic and even sometimes acicular in habit. Their prismatic planes are vertically striated.

The cleavage of rutile is quite distinct parallel to ∞ P(110) and less so parallel to ∞ P ∞ (100).

The mineral is reddish brown, yellowish brown, black or bluish brown by reflected light and sometimes deep red by transmitted light. Many specimens are opaque but some are translucent to transparent.

The latter are often pleochroic in tints varying between yellow and blood-red. The streak is pale brown. The hardness of the mineral is 6 to 6.5 and its density about 4.2. It is an electric nonconductor at ordinary temperatures. Its refractive indices for yellow light are: $\omega = 2.6030$, $\epsilon = 2.8894$.

Rutile is infusible and insoluble. Its reactions with beads of borax and microcosmic salt are usually obscured by the iron present. When this metal is present only in small quantities the microcosmic salt bead is colorless while hot, but violet when cold, if it has been heated for some time in the reducing flame of the blowpipe.

The most characteristic chemical reaction of rutile is obtained upon fusing it with sodium carbonate on charcoal, dissolving the fused mass in

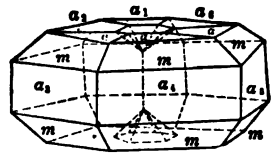


FIG. 83.

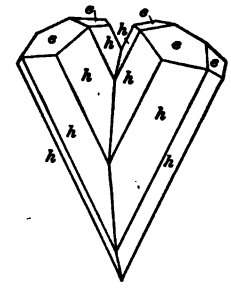


FIG. 84.

FIG. 83.—Rutile Cyclic Sixling Twinned about P∞ (101).

FIG. 84.—Rutile Twinned about 3P∞ (301). Elbow Twin. Forms: ∞P2, 210 (*h*), and P∞, 101 (*e*).

an excess of hydrochloric acid and adding to the solution small scraps of tin. Upon heating for some little time, the solution assumes a violet color. This is a universal test for the metal titanium.

Some of the dark red and reddish brown massive varieties of rutile may be confounded with some varieties of *garnet*, which, however, are much harder. Its density, its infusibility and the reaction for titanium serve to characterize the mineral perfectly.

Pseudomorphs of rutile after hematite and after brookite and anatase have been described. It often changes into ilmenite and sphene.

Syntheses.—By the reaction between $TiCl_4$ and water vapor in a red-hot porcelain tube, crystals of rutile are formed. Twins are produced by submitting precipitated titanic acid in a mass of molten sodium tungstate to a temperature of 1000° for several weeks.

Occurrence and Origin.—Rutile is often found as crystals embedded in limestone and in the quartz or feldspar of granite and other igneous

rocks, as long acicular crystals in slates, and as grains in the rock known as nelsonite. It occurs also as fine hair-like needles penetrating quartz, forming the ornamental stone "flèches d'amour," and as grains in the gold-bearing sand regions. When primary it is probably always a product of magmatic processes, either crystallizing from a molten magma or being the result of pneumatolysis.

Localities.—Handsome crystals of the mineral occur at Arendal, in Norway; in Tyrol, and at St. Gothard and in the Binnenthal, Switzerland. In the United States large crystals have been obtained at Barre, Mass.; at Sudbury, Chester Co., Penn.; at Stony Point, Alexander Co., N. C.; at Graves Mt., in Georgia; at Magnet Cove, in Arkansas, and in Nelson Co., Va. In the latter place it occurs in large quantity as crystals disseminated through a coarse granite rock. The rock containing about 10 per cent of rutile is mined as an ore. It constitutes the principal source of the mineral in the United States. A second type of occurrence in the same locality is a dike-like rock, nelsonite, composed of ilmenite and apatite, in which the ilmenite is in places almost completely replaced by rutile.

Uses.—The mineral is not of great economic importance. It is used in small quantity to impart a yellow color to porcelain and to give an ivory tint to artificial teeth. It is also used in the manufacture of the alloy ferro-titanium which is added to steel to increase its strength. Recently the use of titaniferous electrodes in arc lights, and the use of titanium for filaments in incandescent lamps have been proposed. Some of the salts of titanium are used as dyes and others as mordants. Most of the ferro-titanium made in the United States is manufactured from titaniferous magnetite.

Production.—The only rutile mined in the United States during 1913 came from Roseland, Nelson Co., Virginia. It amounted to 305 tons of concentrates containing about 82 per cent TiO_2. At the same time there were separated about 250 tons of ilmenite (see p. 462)

Polianite (MnO_2) is usually in groups of tiny parallel crystals and as crusts of crystals enveloping crystals of manganite ($MnO \cdot OH$). Their axial ratio is 1 : .6647. The color of the mineral is iron-gray. Its streak is black, its hardness 6–6.5 and density 4.99. It dissolves in HCl evolving chlorine. It is distinguished from *pyrolusite* by its greater hardness and its lack of water. The mineral is extremely rare, being found in measurable crystals only at Platten in Bohemia. It occurs in pseudomorphs after manganite at a number of other points in Europe and at a few points elsewhere, but in most cases it has not been clearly distin-

guished from pyrolusite. The rarity of its crystals is regarded by some mineralogists as being due to the fact that in most of its occurrences polianite is colloidal (a gel).

Plattnerite (PbO_2) is usually massive, but it occurs in prismatic crystals near Mullan in Idaho. Their axial ratio is 1 : .6764. They are usually bounded by $\infty P \infty$ (100), $3P \infty$ (301), $P \infty$ (101), oP (001) and often $\frac{3}{2}P$(332). The mineral is found also in crusts. Its color is iron-black and its streak chestnut-brown. Its hardness is 5–5.5 and its density 8.6. It is brittle and is easily fusible before the blowpipe, giving off oxygen and coloring the flame blue. It yields a lead bead. It is difficultly soluble in HNO_3, but easily soluble in HCl with evolution of chlorine. Plattnerite is found at Leadhills and at Wanlockhead, Scotland, and at the "As You Like" Mine near Mullan, Idaho.

Pyrolusite (MnO_2)

Pyrolusite is often the result of the alteration of the hydroxide, manganite, or of polianite. The few measurable crystals that have been studied seem to indicate that their form is pseudomorphic after the hydroxide. The change by which manganite may pass over into pyrolusite is represented by the reaction $2MnO(OH)+O=2MnO_2+H_2O$. Pyrolusite may be, however, only a slightly hydrated form of polianite.

An analysis of a specimen from Negaunee, Mich., gave:

MnO	O	CaO	BaO	SiO_2	Limonite	H_2O	Total
79.46	17.48	.18	.38	.18	.31	1.94	99.93

Pyrolusite, as usually found, is in granular or columnar masses, or in masses of radiating fibers. It is a soft, black mineral with a hardness of only 2 or 2.5 and a density of about 4.8. Its luster is metallic and its streak black. It is a fairly good conductor of electricity.

The reactions of this mineral are practically the same as those of polianite and manganite (see p. 191), except that only a small quantity of water is obtained from it by heating. Upon strong heating it yields oxygen, according to the equation $3MnO_2=Mn_3+3O_2$.

The manganese minerals are easily distinguished from other minerals by the violet color they give to the borax bead and by the green product obtained when they are fused with sodium carbonate. Pyrolusite is distinguished from *manganite* by its physical properties, and from *polianite* by its softness.

Localities.—Pyrolusite is worked at Elgersberg, near Ilmenau in Thuringia; at Vorder Ehrensdorf in Moravia; at Platten in Bohemia; at Cartersville, Ga.; at Batesville, Ark., and in the Valley of Virginia. A manganiferous silver ore containing considerable quantities of pyrolusite is mined in the Leadville district, Colorado, and large quantities of manganiferous iron ores are obtained in the Lake Superior region.

Uses.—Pyrolusite, together with the other manganese ores with which it is mixed, is the source of nearly all the manganese compounds employed in the arts. Some of the ores, moreover, are argentiferous and others contain zinc. From these silver and zinc are extracted. The most important use of the mineral is in the iron industry. In this industry, however, much of the manganese employed is obtained from manganiferous iron ores. The alloys spiegeleisen and ferro-manganese are employed very largely in the production of an iron used in casting car wheels. It is extremely hard and tough. The manganese minerals are also used in glass factories to neutralize the green color imparted to glass by the ferruginous impurities in the sands from which the glass is made. They are also used in giving black, brown and violet colors to pottery and some of their salts are valuable mordants. Pyrolusite, finally, is the principal compound by the aid of which chlorine and oxygen are produced.

Production.—The United States in 1912 produced about 1,664 tons of manganese ores, valued at $15,723, and all came from Virginia, South Carolina and California. In previous years the ores had been mined also in Arkansas, Tennessee and Utah. Moreover, there were imported into the country 300,661 tons, valued at $1,769,000. Nearly all of this was used in the manufacture of spiegeleisen. The domestic product was used in the chemical industries largely in the manufacture of manganese brick. Of the manganiferous iron ores about 818,000 tons were produced in 1912. These were utilized mainly as ores of iron, though a large portion was used as a flux. The product of manganiferous silver ores aggregated about 48,600 tons, all of which was used as a flux for silver-lead ores. Nearly all of this came from Colorado. In addition there were imported iron-manganese alloys valued at $3,935,000.

Anatase and Brookite (TiO_2)

As has already been stated, the compound TiO_2 is trimorphous, one form being orthorhombic and the two others tetragonal. Of the latter, one has already been described as rutile. The other is anatase, or octahedrite. The orthorhombic form is known as brookite. Anatase and

rutile are separated because of the difference in their axial ratios and in the habits of their crystals. Both are ditetragonal bipyramidal, but $a : c$ for rutile is $1 : .6439$ and for anatase $1 : 1.7771$. Brookite is orthorhombic bipyramidal with $a : b : c = .8416 : 1 : .9444$.

Both anatase and brookite have the same empirical composition, which is similar to that of rutile.

Crystals of *anatase* are usually sharp pyramidal with the form P(111) predominating (Fig. 85), blunt pyramidal with $\frac{1}{3}$P(113) or $\frac{1}{7}$P(117) predominating (Fig. 86), or tabular parallel to oP(001). Twins are common in some localities, with P∞ (101) the twinning plane. The angle $111 \wedge 1\bar{1}1 = 82° 91'$.

The mineral is colorless and transparent, or dark blue, yellow, brown

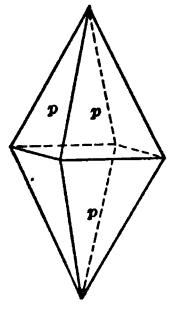


FIG. 85.

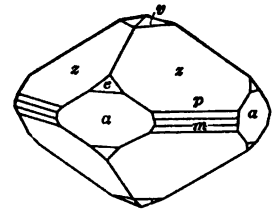


FIG. 86.

FIG. 85.—Anatase Crystal with P, 111 (*p*).

FIG. 86.—Anatase Crystal with $\frac{1}{3}$P, 113 (*z*); P, 111 (*p*); $\frac{1}{7}$P, 117 (*v*); ∞P, 110 (*m*); ∞P∞, 100 (*a*) and P∞, 101 (*e*).

or nearly black and almost opaque. Its streak is colorless to light yellow. Its cleavage is perfect parallel to P and oP and its fracture conchoidal. Its hardness is between 5 and 6 and its density is 3.9. This increases to 4.25 upon heating to a red heat, possibly due to its partial transformation into rutile. The mineral is insoluble in acids except hot concentrated H_2SO_4. It is a nonconductor of electricity. Its indices of refraction for yellow light are: $\omega = 2.5618$, $\epsilon = 2.4886$.

Brookite crystals are usually tabular parallel to ∞P$\bar{\infty}$ (100) and elongated in the direction of the *c* axis. Nearly all crystals are striated in the vertical zone. Although many forms have been identified on them, by far the most common is P$\breve{2}$(122). In some cases this is the only pyramidal form present, as in the type known as *arkansite* (Fig. 87). Twins are rare, with ∞P$\bar{2}$(210) the twinning plane. The angle $111 \wedge 1\bar{1}1 = 64° 17'$.

Brookite may be opaque, translucent or transparent. Its color varies from yellowish brown, through brownish red, to black (arkansite). Its streak is brownish yellow. Its cleavage is imperfect parallel to $\infty P \breve{\infty}$ (101), and its fracture uneven or conchoidal. Its hardness is 5–6 and density about 4. Upon heating its density increases to that of rutile. Its refractive indices for yellow light are: $\alpha = 2.5832$, $\beta = 2.5856$, $\gamma = 2.7414$. It fuses at about 1560°, and is insoluble in acids.

The chemical properties of both brookite and anatase are similar to those of rutile. They are distinguished from *rutile* by their physical properties and their crystallization.

Both brookite and anatase alter to rutile.

Syntheses.—Upon heating TiF_4 with water vapor at a temperature

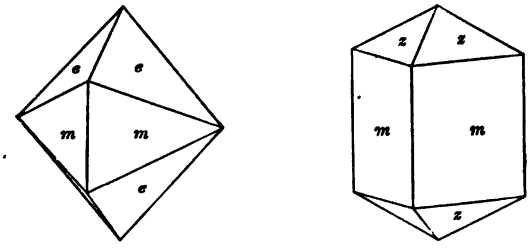


FIG. 87.—Brookite Crystals with ∞P, 110 (*m*); $\frac{1}{2}P$, 112 (*z*) and $P\breve{2}$, 122 (*e*). The combination *m* and *e* is characteristic for Arkansite.

below that of vaporizing cadmium, crystals of anatase are produced. If the temperature is raised above the point of vaporization of cadmium and kept below that of zinc, crystals of brookite result.

Occurrence.—Brookite and anatase occur as crystals on the walls of clefts in crystalline silicate rocks and in weathered phases of volcanic rocks. They are mainly pneumatolytic products, the production of the one or the other depending upon the temperature at which the TiO_2 was deposited.

Localities.—Fine brookite crystals are found at St. Gothard, in Switzerland; at Pregrattan, in the Tyrol; near Tremadoc, in Wales; at Miask, in Russia, and at Magnet Cove, Arkansas.

Anatase crystals are less common than those of brookite but they occur at many points in Switzerland, especially in the Binnenthal; near Bourg d'Oisans, France; at many points in the Urals, Russia; in the diamond fields of Brazil, and at the brookite occurrences in Arkansas.

CHAPTER VIII

THE HYDROXIDES

THE hydroxides, as has already been explained, may be looked upon as derivatives of water, in which only a portion of the hydrogen has been replaced. The group includes several minerals of economic importance, among which is the fine gem mineral opal. All the hydroxides yield water when heated in a glass tube, but they do not yield it as readily as do salts containing water of crystallization.

A few of the hydroxides may act as acids forming salts with metals. Diaspore, for instance, is an hydroxide of aluminium $AlO \cdot OH$, or $Al\begin{cases} O-H \\ O \end{cases}$, which appears to be able to form salts; at least, the chemical composition of some of the members of an important group of minerals, the spinels, may be explained by regarding them as salts of this acid (see p. 195).

Opal (SiO_2+Aq)

The true position of opal in the classification of minerals is somewhat doubtful. From the analyses made it appears to be a combination of amorphous silica and water, or, perhaps, a mixture of silica in some form and a hydroxide of silicon. The percentage of water present is variable. In some specimens it is as low as 3 per cent, while in others it is as high as 13 per cent. The mineral is not known in crystals. It is probably a colloid, in which the water is, in part at least, mechanically held in a gel of SiO_2. It occurs only in massive form, in stalactitic or globular masses and in an earthy condition.

When pure the mineral is colorless and transparent. Usually, however, it is colored some shade of yellow, red, green or blue, when it is translucent or sometimes even opaque. The red and yellow varieties contain iron oxides and the green, *prasopal*, some nickel compound. The play of color in gem opal is due to the interference of light rays reflected from the sides of thin layers of opal material with different densities from that of the main mass of the mineral they traverse. The hardness of opal is 5.5–6.5 and its density about 2.1. Its refractive index for yellow light, $n = 1.4401$. It is a nonconductor of electricity.

The principal varieties of opal are:

Precious opal, a transparent variety exhibiting a delicate play of colors,

Fire opal, a precious opal in which the colors are quite brilliant shades of red and yellow,

Girasol, a bluish white translucent opal with reddish reflections,

Common opal, a translucent variety without any distinct play of colors,

Cachalong, an opaque bluish white, porcelain-like variety,

Hyalite, a transparent, colorless variety, usually in globular or botryoidal masses, and

Siliceous sinter, white, translucent to opaque pulverulent accumulations and hard crusts, deposited from the waters of geysers and other hot springs.

Tripolite and *infusorial earth* are pulverulent forms of silica in which opal is an important constituent. Tripoli is a light porous siliceous rock, supposed to have resulted from the leaching of calcareous material from a siliceous limestone. Infusorial earth represents the remains of certain aquatic forms of microscopic plants known as diatoms.

Flint and *Chert* are mixtures of opal, chalcedony and quartz.

All varieties of opal are infusible and all become opaque when heated. When boiled with caustic alkalies some varieties dissolve easily, while others dissolve very slowly.

Syntheses.—Coatings of material like opal have been noted in glass flasks containing hydrofluosilicic acid that had not been opened for several years. Opal has also been obtained by the slow cooling of a solution of silicic acid in water.

Occurrence.—The mineral occurs as deposits around hot springs. It also forms veins in volcanic rocks and is embedded in certain limestones and slates, where it is probably the result of the solution of the siliceous spicules and shells of low forms of life and subsequent deposition. It also results from the solution of the calcite from limestones containing finely divided silica.

It is not an uncommon alteration product of silicates. It seems to have been deposited from both cold and hot water.

Localities.—Precious opal is found near Kashan, in Hungary; at Zimapan, Quaretaro, in Mexico; in Honduras; in Queensland and New South Wales, Australia, and in the Faroe Islands. Common opal is abundant at most of these localities and is found also in Moravia, Bohemia, Iceland, Scotland and the Hebrides. Hyalite occurs in small quantity at several places in New York, New Jersey, North Carolina,

Georgia and Florida, and common opal, at Cornwall, Penn., and in Calaveras Co., California. Common opal and varieties exhibiting a little fire have recently been explored in Humboldt and Lander Counties, Nevada. Siliceous sinter is deposited at the Steamboat Springs in Nevada and *geyserite* (a globular form of the sinter) at the mouths of the geysers in the Yellowstone National Park.

Uses.—The precious and fire opals are popular and handsome gems. Opalized wood, i.e., wood that has been changed into opal in such a manner as to retain its woody structure, is often cut and polished for use as an ornamental stone. Infusorial earth, a white earthy deposit of microscopic shells consisting largely of opal material, possesses many uses. It is employed in the manufacture of soluble glass, polishing powders, cements, etc., and as the "body," which, saturated with nitroglycerine, composes dynamite. Tripoli, a mixture of quartz and opal, is used as a wood filler, in making paint, as an abrasive and in the manufacture of filter stones. The principal sources of commercially valuable opal material in the United States are the opalized forest in Apache Co., Ariz., the infusorial earth beds at Pope's Creek and Dunkirk, Md., various places in Napa Co., Cal., at Virginia City, Nev., and at Drakesville, N. J., and the tripoli beds in the neighborhood of Stella, Mo., and the adjoining portion of Illinois.

Production.—The total quantity of infusorial earth and tripoli mined during 1912 was valued at $125,446. The aggregate value of precious opal obtained in 1912 was $10,925. This came from California and Arizona.

Brucite ($Mg(OH)_2$)

Brucite is the hydroxide of magnesium. It is a white, soft mineral usually occurring in crystals or in foliated masses.

Analyses of the mineral correspond very closely to the formula $Mg(OH)_2$ which requires 41.38 per cent Mg, 27.62 per cent O and 31.00 per cent H_2O, though they usually show the presence of small quantities of iron and manganese. A specimen from Reading, Penn., yielded:

MgO	Fe_2O_3	MnO	H_2O	Total
67.64	.82	.63	30.92	100.01

The crystallization of brucite is hexagonal (ditrigonal scalenohedral), $a : c = 1 : 1.5208$. The crystals are tabular in habit in consequence of the broad development of the basal plane oP(0001). The other forms present are $R(10\bar{1}1)$, $-4R(04\bar{4}1)$ and $-\frac{1}{3}R(01\bar{1}3)$ (Fig. 88). The angle $10\bar{1}1 \wedge \bar{1}101 = 97° 38'$.

The cleavage of brucite is very perfect parallel to oP(001), and folia that may be split off are flexible. The mineral is sectile. Its hardness is 2.5 and its density 2.4. Its color is white, inclining to bluish and greenish tints, and its luster pearly on oP. Brucite is transparent to translucent. It is pyroelectric and a non-conductor of electricity. Its refractive indices for red light are: $\omega = 1.559$, $\epsilon = 1.579$.

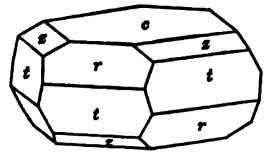


FIG. 88.—Brucite Crystal with oR, 0001 (*c*); R, $10\bar{1}1$ (*r*); $-\frac{1}{3}$R, $01\bar{1}3$ (*z*) and -4R, $04\bar{4}1$ (*t*).

In the closed tube brucite, like other hydroxides, yields water. The mineral is infusible. When intensely heated, it glows. After heating, it reacts alkaline. When moistened with cobalt nitrate solution and heated, it turns pink, the characteristic reaction for magnesium. The pure mineral is soluble in acids.

Brucite resembles in many respects gypsum, talc, diaspore and some micas. It is distinguished from *diaspore* and *mica* by its hardness and from talc by its solubility in acids. *Gypsum* is a sulphate, hence the test for sulphur will sufficiently characterize it.

Synthesis.—Crystals have been made by precipitating a solution of magnesium chloride with an alcoholic solution of potash, dissolving the precipitate by heating with an excess of KOH and allowing to cool.

Occurrence and Origin.—Brucite is usually associated with other magnesium minerals. It is often found in veins cutting the rock known as serpentine, where it is probably a weathering product, and is sometimes found in masses in limestone, especially near its contact with igneous rocks.

Localities.—It occurs crystallized in one of the Shetland Islands; at the Tilly Foster Iron Mine, Brewster, N. Y.; at Woods Mine, Texas, Penn., and at Fritz Island, near Reading, in the same State.

Gibbsite ($Al(OH)_3$)

Gibbsite, or hydrargillite, is utilized to some extent as an ore of aluminium. It occurs as crystals, in granular masses, in stalactites and in fibrous, radiating aggregates.

Its theoretical composition demands 65.41 per cent Al_2O_3 and 34.59 per cent H_2O. Usually, however, the mineral is mixed with bauxite ($Al_2O(OH)_4$) and in addition contains also small quantities of iron, magnesium, silicon and often calcium.

Crystals are monoclinic with $a : b : c = 1.709 : 1 : 1.918$ and $\beta = 85° 29\frac{1}{6}'$. Their habit is tabular. Besides the basal plane, oP(001), the

two most prominent forms are $\infty P\bar{\infty}$ (100) and ∞P(110). Thus the plates have hexagonal outlines. They have a perfect cleavage parallel to the base. Twinning is common, with oP(001) the twinning plane.

The mineral has a glassy luster except on the basal plane where its luster is pearly. It is transparent or translucent, white, pink, green or gray. Its streak is light, its hardness is 2–3 and specific gravity 2.35. It is a nonconductor of electricity. Its refractive indices are: $\alpha=\beta=1.5347$, $\gamma=1.5577$.

When heated before the blowpipe the mineral exfoliates, becomes white, glows strongly but does not fuse. Upon cooling the heated mass is hard enough to scratch glass. The mineral dissolves slowly but completely in hot HCl and in strong H_2SO_4, and gives a blue color when moistened with $Co(NO_3)_2$ solution and heated.

Gibbsite resembles most closely *bauxite*, from which it is distinguished principally by its structure. It differs from *wavellite* (p. 287), which it also sometimes resembles, in the absence of phosphorus.

Syntheses.—Crystals of gibbsite have been made by heating on a water bath a saturated solution of $Al(OH)_3$ in dilute ammonia until all of the ammonia evaporates; and also by gradually precipitating the hydroxide from a warm alkaline solution by means of a slow stream of CO_2.

Occurrence.—The mineral rarely occurs in pure form. It is found in veins and in cavities in various schistose and igneous rocks. It is probably a weathering product of aluminous silicates.

Localities.—Gibbsite has been reported as existing in small quantities at various points in Europe, near Bombay, India, and at several places in South America and Africa. In the United States it occurs at Richmond, Mass., at Union Vale, Dutchess Co., N. Y., and mixed with bauxite at several of the occurrences of this mineral (see page 186).

Uses.—It is mined with bauxite as a source of aluminium.

Limonite ($Fe_4O_3(OH)_6$)

Limonite is an earthy or massive reddish brown mineral whose composition and crystallization are but imperfectly known. It is an important iron ore called in the trade "brown hematite."

The analyses of limonite range between wide limits, largely because of the great quantities of impurities mixed with it. The formula demands 59.8 per cent Fe, 25.7 per cent O and 14.5 per cent water, but the percentages of these constituents found in different specimens only approximately correspond to these figures. Many mineralogists regard

FIG. 89.—Limonite Stalactites in Silverbow Mine, Butte, Mont. (*After W. H. Weed.*)

FIG. 90.—Botryoidal Limonite.

limonite as colloidal goethite ($FeO \cdot OH$) with one molecule or more of H_2O, depending upon temperature. The principal impurities are clay, sand, phosphates, silica, manganese compounds and organic matter. The great variety of these is thought to be due to the fact that the limonite, like other gels, possesses the power of absorbing compounds from their solution, so that the mineral is in reality a mixture of colloidal iron hydroxide and various compounds which differ in different occurrences.

The mineral occurs in stalactites (Fig. 89), in botryoidal forms (Fig. 90), in concretionary and clay-like masses and often as pseudomorphs after other minerals and after the roots, leaves and stems of trees.

Limonite is brown on a fresh fracture, though the surface of many specimens is covered with a black coating that is so lustrous as to appear varnished. Its streak is yellowish brown. Its hardness is a little over 5 and its density about 3.7. The mineral is opaque and its luster is dull, silky or almost metallic according to the physical conditions of the specimen. Its index of refraction is about 2.5. It is a nonconductor of electricity.

The varieties recognized are: *compact*, the stalactitic and other fibrous forms; *ocherous*, the brown or yellow earthy, impure variety; *bog iron*, the porous variety found in marshes, pseudomorphing leaves, etc., and *brown clay ironstone*, the compact, massive or nodular form.

In its chemical properties limonite resembles *goethite*, from which it can be distinguished only with great difficulty except when the latter is in crystals. From uncrystallized varieties of goethite it can usually be distinguished only by quantitative analysis, although in pure specimens the streaks are different.

Occurrence and Origin.—Limonite is the usual result of the decomposition of other iron-bearing minerals. Consequently, it is often found in pseudomorphs. In almost all cases where large beds of the ore occur the material has been deposited from ferriferous water rich in organic substances. One of the commonest types of occurrence is "gossan." In the production of this type of ore, those portions of veins carrying ferruginous minerals are oxidized under the influence of oxygen-bearing waters, forming a layer composed largely of limonite which covers the upper portion of the veins and hides the original vein matter. Gossan ores derived from chalcopyrite and pyrite are common in all regions in which these minerals occur. Another type of limonitic ore comprises those found in clays derived from limestones by weathering. In such deposits the ore occurs as nodules and in pockets in the clay. Ores of

this type are common in the valleys within the Appalachian Mountains. Bog iron ores occur in swamps and lakes into which ferruginous solutions drain. The iron may come from pyrite or iron silicates in the drainage basins of the lakes or swamps. When carried down it is oxidized by the air and sinks to the bottom.

Localities.—The mineral occurs abundantly and in many different localities. The most important American occurrences are extensive beds at Salisbury and Kent, Conn.; at many points in New Jersey, Pennsylvania, Michigan, Tennessee, Alabama, Ohio, Virginia and Georgia.

Uses.—Although containing less iron than hematite, on account of its cheapness, and the ease with which it works in the furnace, brown hematite is an important ore of this metal. The earthy varieties are used as cheap paints.

Production.—The yield of the United States "brown hematite" mines for 1912 was a little over 1,600,000 tons. Of this amount the largest yields were:

Alabama	749,242 tons
Virginia	398,833 tons
Tennessee	171,130 tons

The quantity of ocher produced in the United States during the same year amounted to about 15,269 tons, valued at $149,289. Most of it came from Georgia. In addition, 8,020 tons were imported. This had a value of $148,300.

Bauxite ($Al_2O(OH)_4$)

Bauxite, or beauxite, like limonite, is probably a colloid. At any rate it is unknown in crystals. Until recently it possessed but little value. It is now, however, of considerable importance as it is the principal source of the aluminium on the market.

The mineral is apparently an hydroxide of aluminium with the formula $Al_2O(OH)_4$ or $Al_2O_3 \cdot 2H_2O$ in which 26.1 per cent is water and 73.9 per cent alumina (Al_2O_3), but it may be a colloidal mixture of the gibbsite and diaspore (p. 190) molecules, or of various hydroxides, since its analyses vary within wide limits. A sample of very pure material from Georgia gave on analysis:

Al_2O_3	Fe_2O_3	SiO_2	TiO_2	H_2O
62.46	.81	4.72	.23	31.03

Bauxite occurs in concretionary grains (Fig. 91), in earthy, clay-like forms and massive, usually in pockets or lenses in clay resulting from the weathering of limestones or of syenite. It is white when pure, but as usually found is yellow, gray, red or brown in color, is translucent to opaque and has a colorless or very light streak. Its density is 2.55 and its hardness anywhere between 1 and 3. Its luster is dull. It is a nonconductor of electricity.

Before the blowpipe bauxite is infusible. In the closed tube it yields

FIG. 91.—Pisolitic Bauxite, from near Rock Run, Cherokee Co., Ala.

water at a high temperature. Its powder when intensely heated with a few drops of cobalt nitrate solution turns blue. The mineral is with difficulty soluble in hydrochloric acid.

Occurrence and Origin.—Bauxite in some cases may be a deposit from hot alkaline waters, but in Arkansas it is a residual weathering product of the igneous rock, syenite. It occurs in beds associated with corundum, clay, gibbsite and other aluminium minerals.

Localities.—Large deposits of the ore occur at Baux, near Arles, France; near Lake Wochein, in Carniola; in Nassau; at Antrim, Ireland; in a stretch of country between Jacksonville, Fla., and Carters-

ville, Ga.; in Saline and Pulaski Counties, Ark.; in Wilkinson Co., Ga., and near Chattanooga, Tenn.

Preparation.—The ore is mined by pick and shovel, crushed and washed. It is then, in some cases, dried and broken into fine particles. The fine dust is separated from the coarser material, and the latter, which comprises most of the ore, is heated to 400°. This changes the iron compounds to magnetic oxide which is separated electro-magnetically. The concentrate contains about 86 per cent of Al_2O_3. This is then purified and dissolved in a molten flux, in some cases cryolite, and is subjected to electrolysis. The quantity of aluminium made in the United States during 1912 was over 65,600,000 lb., valued at about $17,000,000. The value of the aluminium salts produced was about $3,000,000.

Uses.—Bauxite (or more properly the mixture of bauxite and gibbsite) is practically the only commercial ore of aluminium which, on account of its lightness and its freedom from tarnish on exposure, has become a very popular metal for use in various directions. It is employed in castings where light weight is desired and in the manufacture of ornaments and of plates for interior metallic decorations. It is also employed in the steel industry, and, in the form of wire, for the transmission of electricity. The mineral is also used in the manufacture of aluminium salts, in making alundum (artificial corundum), and bauxite brick for lining furnaces, and in the manufacture of paints and alloys.

Production.—The bauxite mined in the United States during 1912 amounted to about 159,865 tons valued at $768,932, the greater portion coming from Arkansas. This is about two-thirds the value of the production of the entire world.

Psilomelane

Psilomelane is probably a mixture of colloidal oxides and hydroxides of manganese in various proportions. In most specimens there is a notable percentage of BaO or K_2O present, and in others small quantities of lithium and thallium. The barium and potassium components are thought to have been absorbed from their solutions.

The substance occurs in globular, botryoidal, stalactitic, and massive forms exhibiting, in many instances, an obscure fibrous structure. Its color is black or brownish black and its streak brownish black and glistening. Its hardness is 5.5–6 and specific gravity 4.2.

Psilomelane is infusible before the blowpipe, in some cases coloring the flame green (Ba) and in others violet (K). With fluxes it reacts for

manganese. In the closed tube it yields water. It is soluble in HCl with evolution of chlorine.

It is distinguished from most other manganese oxides and hydroxides by its greater hardness.

Occurrence.—Psilomelane occurs in veins associated with pyrolusite and other manganese compounds, as nodules in clay beds, and as coatings on many manganiferous minerals. In all cases it is probably a product of weathering.

Localities.—It is found in large quantity at Elgersburg in Thüringia; at Ilfeld, Harz; and at various places in Saxony. In the United States it occurs with pyrolusite and other ores of manganese at Brandon, Vt.; in the James River Valley, and the Blue Ridge region of Virginia; in northeastern Tennessee; at Cartersville, Georgia; at Batesville, Arkansas; and in a stretch of country about forty miles southeast of San Francisco, California. At many of these points it has been mined as an ore of manganese.

Wad

Wad is a soft, earthy, black or dark brown aggregate of manganese compounds closely related to psilomelane.

It occurs in globular, botryoidal, stalactitic, flaky and porous masses, which, in some cases, are so light that they float on water. It also occurs in fairly compact layers and coats the surfaces of cracks, often forming branching stains, known as dendrites.

Wad contains more water than psilomelane, of which it appears often to be a decomposition product. More frequently it results from the weathering of manganiferous iron carbonate. It is particularly abundant in the oxidized portions of veins containing manganese carbonates and silicates.

Wad is easily distinguished from all other soft black minerals, except *pyrolusite*, by the reaction for manganese, and from all other manganese compounds, except pyrolusite, by its softness. From pyrolusite it is distinguished by its content of water.

Localities.—It occurs in most of the localities at which other manganese compounds are found.

DIASPORE GROUP

The diaspore group comprises the hydroxides of aluminium, iron and manganese, possessing the general formula $R'''O(OH)$. They are regarded as hydroxides in which one of the hydrogens in H_2O is replaced by the group $R'''O$, thus: H—O—H, water, AlO—O—H, diaspore. These

three compounds from a chemical viewpoint, may be looked upon as the acids whose salts comprise the spinel group of minerals, which includes among others the three important ore minerals *magnetite*, *chromite* and *franklinite*. Of the three members of the diaspore group the manganese and iron compounds are valuable ores. All are orthorhombic, in the rhombic bipyramidal class.

Diaspore ($AlO(OH)$)

Diaspore is found in colorless or light colored crystals, in foliated masses and in stalactitic forms.

Its composition is theoretically 85 per cent Al_2O_3 and 15 per cent

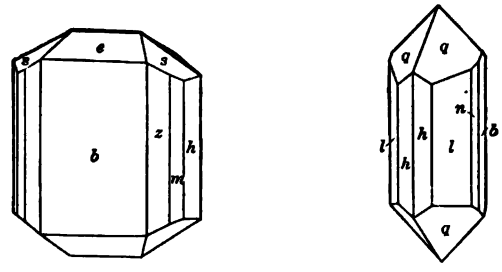


FIG. 92.—Diaspore Crystals. $\infty P\breve{\infty}$, 010 (*b*); $\infty P\breve{3}$, 130 (*z*); ∞P, 110 (*m*); $\infty P\bar{2}$, 210 (*h*); $P\breve{\infty}$, 011 (*e*), $P\bar{2}$, 212 (*s*); $\infty P\breve{2}$, 120 (*l*); $\infty P\breve{5}$, 150 (*n*); $\frac{3}{2}P\breve{\frac{3}{2}}$, 232 (*q*).

H_2O, though analyses show it to contain, in addition, usually, some iron and silicon. A specimen from Pennsylvania yielded:

Al_2O_3	H_2O	Fe_2O_3	SiO_2	Total
80.95	14.84	3.12	1.53	100.44

Other specimens approach the theoretical composition very closely.

In crystallization the mineral is orthorhombic (rhombic bipyramidal class), with $a : b : c = .9372 : 1 : .6039$. The crystals are usually prismatic, though often tabular parallel to $\infty P\breve{\infty}$ (010). The principal planes observed on them are $\infty P\breve{\infty}$ (010), a series of prisms as ∞P(110), $\infty P\bar{2}$(210), $\infty P\breve{3}$(130), the dome $P\breve{\infty}$ (011) and several pyramids (Fig. 92). The planes of the prismatic zone are often vertically striated. The angle $110 \wedge 1\bar{1}0 = 86° 17'$.

The cleavage of diaspore is very distinct parallel to the brachypinacoid. Its fracture is conchoidal and the mineral is very brittle. Its hardness is about 6.5 and density 3.4. The luster of the mineral is vitreous, except on the cleavage surface, where it is pearly. Its color

varies widely, though the tint is always light and the streak colorless. The predominant shades are bluish white, grayish white, yellowish or greenish white. The mineral is transparent or translucent. It is a nonconductor of electricity. Its refractive indices for yellow light are: $\alpha = .1702$, $\beta = 1.722$, $\gamma = 1.750$.

In the closed tube diaspore decrepitates and gives off water at a high temperature. It is infusible and insoluble in acids. When moistened with a solution of cobalt nitrate and heated it turns blue, as do all other colorless aluminium compounds.

In appearance, diaspore closely resembles *brucite* ($Mg(OH)_2$), from which it may be distinguished by its greater hardness and its aluminium reaction with cobalt nitrate.

Synthesis.—Crystal plates of diaspore have been made by heating at a temperature of less than 500°, an excess of amorphous Al_2O_3 in sodium hydroxide, enclosed in a steel tube. At a higher temperature corundum resulted.

Occurrence.—Diaspore occurs as crystals implanted on corundum and other minerals, and on the walls of rocks in which corundum is found. It is probably in most cases a decomposition product of other aluminium compounds.

Localities.—In Ekaterinburg, Russia, it is associated with emery. At Schemnitz, Hungary, it occurs in veins. It is found also in the Canton of Tessin, in Switzerland, at various places in Asia Minor, and on the emery-bearing islands of the Grecian Archipelago. In the United States it is associated with corundum, at Newlin, Chester Co., Penn., with emery at Chester, Mass., at the Culsagee corundum mine, near Franklin, N. C., and at other corundum mines in the same State.

Manganite ($MnO(OH)$)

Manganite usually occurs in groups of black columnar or prismatic crystals and in stalactites.

The formula $MnO(OH)$ requires 27.3 per cent O, 62.4 per cent Mn and 10.3 per cent water, or 89.7 per cent MnO and 10.3 per cent water. In addition to these constituents, the mineral commonly contains also some iron, magnesium, calcium and often traces of other metals. An analysis of a specimen from Langban, in Sweden, yielded:

Mn_2O_3	Fe_2O_3	MgO	CaO	H_2O	Total
88.51	.23	1.51	.62	9.80	100.67

The orthorhombic crystals of the mineral have an axial ratio $a : b : c = .8441 : 1 : .5448$. The crystals are nearly all columnar with a series

of prisms, among which are $\infty P\bar{4}(410)$ and $\infty P(110)$, and the two lateral pinacoids $\infty P\breve{\infty}(010)$ and $8 P\bar{\infty}(100)$ terminated by $oP(001)$ or by the domes $P\breve{\infty}(011)$, $P\bar{\infty}(101)$, and pyramids (Figs. 93 and 94). Cruciform and contact twins, with the twinning plane $P\breve{\infty}(011)$, are not uncommon (Fig. 95). The prismatic surfaces are vertically striated and the crystals are often in bundles. The angle $110 \wedge 1\bar{1}0 = 80° 20'$.

FIG. 93. — Manganite Crystal with ∞P, 110 (*m*); oP, 001 (*c*) and $P\bar{\infty}$, 101 (*n*).

Cleavage is well defined parallel to $\infty P\breve{\infty}(010)$ and less perfectly developed parallel to $\infty P(110)$. The fracture is uneven. The luster of the mineral is brilliant, almost metallic. Its color is iron-black and its streak reddish brown or nearly black. It is usually opaque but in very thin splinters it is sometimes brown by transmitted light. Its hardness is 4 and density about 4.3. The mineral is a nonconductor of electricity.

Manganite yields water in the closed tube and colors the borax bead amethyst in the oxidizing flame of the blowpipe. In the reducing flame, upon long-continued heating, this color disappears. The mineral dissolves in hydrochloric acid with the evolution of chlorine. It is distinguished from other manganese minerals by its hardness and crystallization.

FIG. 94.—Group of Prismatic Manganite Crystals from Ilfeld, Harz.

By loss of water manganite passes readily into pyrolusite (MnO_2). It also readily alters into other manganese compounds.

Synthesis.—Upon heating for six months a mixture of manganese chloride and clcium caarbonate fine crystals like those of manganite

have been obtained. Their composition, however, was that of *hausmannite*, indicating that while manganite was produced, it was changed to hausmannite during the process.

Occurrence, Localities and Origin.—Manganite occurs in veins in old volcanic rocks, and also in limestone. It is found at Ilfeld in the Harz; at Ilmenau in Thüringia, and at Langban in Sweden, in handsome crystals. In the United States it occurs at the Jackson and the Lucie iron mines, Negaunee, Mich., and in Douglas Co., Colo. It is also abundant at various places in New Brunswick and Nova Scotia. In all cases it is a residual product of the weathering of manganese compounds.

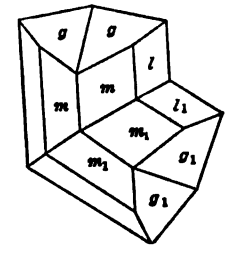


FIG. 95.—Manganite Crystal Twinned about P $\breve{\infty}$ (011). The forms are ∞ P, 110 (*m*); ∞ P$\breve{2}$, 120 (*l*) and P3, 313 (*g*).

Uses.—Manganite is used in the production of manganese compounds. As mined it is usually mixed with pyrolusite, this being the most important portion of the mixture.

Goethite ($FeO(OH)$)

This mineral, though occasionally found in blackish brown crystals, usually occurs in radiated globular and botryoidal masses. Analyses of specimens from Maryland, and from Lostwithiel, in Cornwall, gave:

	Fe_2O_3	Mn_2O_3	H_2O	SiO_2	Total
Maryland.....	86.32	...	10.80	2.88	100.00
Lostwithiel.....	89.55	.16	10.07	.28	100.06

The formula $FeO(OH)$ demands 89.9 per cent Fe_2O_3 and 10.1 per cent H_2O or 62.9 per cent Fe, 27.0 per cent O and 10.1 per cent H_2O.

Like diaspore and manganite, goethite is orthorhombic, its axial ratio being $a : b : c = .9185 : 1 : .6068$. Its crystals are prismatic or acicular with the prisms plainly striated vertically. The forms observed are commonly ∞ P $\breve{\infty}$ (010), ∞ P$\bar{2}$(210), ∞ P(110), P $\breve{\infty}$ (011) and P(111). The angle $110 \wedge 1\bar{1}0 = 85° 8'$.

The cleavage of goethite is perfect parallel to ∞ P $\breve{\infty}$ (010) and its fracture uneven. Its hardness is 5 and density about 4.4. Its color is usually yellowish, reddish or blackish brown and its luster almost metallic. In thin splinters it is often translucent with a blood-red color and a refractive index of about 2.5. Its streak is brownish yellow. It is an electric nonconductor.

The chemical reactions of the mineral are about the same as those of hematite, except that it yields water when heated in the closed tube. By this reaction it is easily distinguished from the fibrous varieties of *hematite*, as it is also by its streak.

Synthesis.—Needles of goethite are produced by heating freshly precipitated iron hydroxide for a long time at 100°.

Occurrence and Localities.—Goethite is usually associated with other ores of iron, especially in the upper portion of veins, where it is produced by weathering. It is found near Siegen in Nassau; near Bristol and Clifton, England, and in large, fine crystals at Lostwithiel and other places in Cornwall.

In the United States it occurs in small quantity at the Jackson and the Lucie hematite mines in Negaunee, Mich.; at Salisbury, Conn.; at Easton, Penn., and at many other places.

Uses.—Goethite is used as an ore of iron, but in the trade it is classed with limonite as brown hematite.

CHAPTER IX

THE ALUMINATES, FERRITES, CHROMITES AND MANGANITES

MOST of these compounds are salts of the comparatively uncommon acids $HAlO_2$, $HFeO_2$ and $HCrO_2$, which may be regarded as metaacids derived from the corresponding normal acids by the abstraction of water, thus: $H_3AlO_3 - H_2O = HAlO_2$. There are only a few minerals belonging to the group but they are important. One, magnetite, is an ore of iron; another, chromite, is the principal ore of chromium and two others are utilized as gems. Most of them are included in the mineral group known as the spinels. (Compare p. 189.)

That there is a manganese acid corresponding to the metaacids of Al, Fe and Cr is indicated by the fact that in some of the spinels manganese replaces some of the ferric iron, as, for example, in franklinite. This suggests that this mineral is an isomorphous mixture of a metaferrite and a salt of the corresponding manganese acid ($HMnO_2$). This may be regarded as derived from the hydroxide, $Mn(OH)_3$, by abstraction of H_2O, thus: $H_3MnO_3 - H_2O = HMnO_2$. But there are other manganous acids. Normal manganous acid is $Mn(OH)_4$, or H_4MnO_4. If from this one molecule of water be abstracted, there remains H_2MnO_3, the metamanganous acid. The manganous salt of the normal acid, Mn_2MnO_4, occurs as the mineral, hausmannite, and the corresponding salt of the metaacid, $MnMnO_3$, as the mineral, braunite.

SPINEL GROUP

The spinels are a group of isomorphous compounds that may be regarded as salts of the acids AlO(OH), MnO(OH), CrO(OH) and FeO(OH), in which the hydrogen is replaced by Mg, Fe and Cr. Thus, *spinel*, $Mg \cdot Al_2O_4$ may be regarded as $\begin{matrix} Al-O-O \\ \| \\ Al-O-O \end{matrix}\!\!>\!Mg$; *magnetite*, Fe_3O_4, as $\begin{matrix} Fe-O-O \\ \| \\ Fe-O-O \end{matrix}\!\!>\!Fe$; *chromite*, $FeCr_2O_4$, as $\begin{matrix} Cr-O-O \\ \| \\ Cr-O-O \end{matrix}\!\!>\!Fe$; and *franklinite*, as $\begin{matrix} (Fe \cdot Mn)-O-O \\ | \quad | \\ (Fe \cdot Mn)-O-O \end{matrix}\!\!>\!(Zn \cdot Mn \cdot Fe)$. Chemical compounds of

this general type are fairly numerous, but only a few occur as minerals. The most important are the three important ores mentioned above; spinel is of some value as a gem stone.

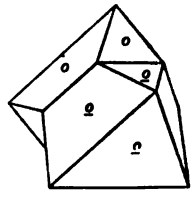


FIG. 96.
Spinel Twin.

The spinels crystallize in the holohedral division of the isometric system (hexoctahedral class), in well defined crystals that are usually combinations of O(111) and ∞O(110), with the addition on some of ∞O∞ (100), 3O3(311), 2O2(211), 5O$\frac{5}{3}$(531), etc. Contact twins are so common with O the twinning plane, that this type of twinning is often referred to as the spinel twinning (Fig. 96).

The complete list of the known spinels is as follows:

Spinel	$Mg(AlO_2)_2$
Ceylonite (pleonaste)	$(Mg \cdot Fe)(AlO_2)_2$
Chlorspinel	$Mg((Al \cdot Fe)O_2)_2$
Picotite	$(Mg \cdot Fe)((Al \cdot Fe \cdot Cr)O_2)_2$
Hercynite	$Fe(AlO_2)_2$
Gahnite	$Zn(AlO_2)_2$
Dysluite	$(Zn \cdot Fe \cdot Mn)((Al \cdot Fe)O_2)_2$
Kreittonite	$(Zn \cdot Fe \cdot Mg)\ ((Al \cdot Fe)O_2)_2$
Magnetite	$Fe(FeO_2)_2$
Magnesioferrite	$Mg(FeO_2)_2$
Franklinite	$(Fe \cdot Zn.Mn)((Fe \cdot Mn)O_2)_2$
Jacobsite	$(Mn \cdot Mg)((Fe \cdot Mn)O_2)_2$
Chromite	$(Fe \cdot Mg)(Cr \cdot Fe)O_2)_2$

Spinel ($Mg(AlO_2)_2$)

Ordinary spinel is the magnesian aluminate, which, when pure, contains 28.3 per cent MgO and 71.7 per cent Al_2O_3. Usually, however, there are present admixtures of the other isomorphs so that analyses often indicate Fe, Al and Cr.

The mineral usually occurs in isolated simple crystals, rarely in groups. The forms observed on them are O(111), ∞O(110) and 3O3(311), and rarely ∞O∞ (100) (Fig. 97).

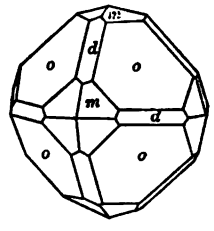


FIG. 97.—Spinel Crystal with O, 111 (*o*); ∞O, 110 (*d*) and 3O3, 311 (*m*).

The pure magnesium spinel is colorless or some shade of pink or red, brown or blue, and is usually transparent or translucent, though opaque varieties are not rare. Its streak is white. It possesses a glassy

luster, and a conchoidal fracture, but no distinct cleavage. Its hardness is 8 and its density 3.5–3.6. Its refractive indices vary with the color: *n* for yellow light is 1.7150 for red spinel and 1.7201 for the blue variety.

The mineral is infusible before the blowpipe and is unattacked by acids. It yields the test for magnesia with cobalt solution.

Spinel is easily distinguished from most other minerals by its crystallization and hardness. It is distinguished from pale-colored *garnet* by its blowpipe reactions, especially its infusibility, and its failure to respond to the test for SiO_2.

The best known varieties are:

Precious spinel, which is the pure magnesian aluminate. It is transparent and colorless or some light shade of red, blue or green. The bright red variety is known as *ruby spinel* and is used as a gem. Its color is believed to be due to the presence of chromium oxide. It is easily distinguished from genuine ruby by the fact that it is not doubly refracting and not pleochroic.

The best ruby spinels come from Ceylon, where they occur loose in sand associated with zircon, sapphire, garnet, etc.

Common spinel differs from precious spinel in that it is translucent. It usually contains traces of iron and alumina.

Both these varieties of spinel occur in metamorphosed limestones and crystalline schists.

Syntheses.—The spinels have been made by heating a mixture of Al_2O_3 and MgO with boracic acid until fusion ensues; and by heating $Mg(OH)_2$ with $AlCl_3$ in the presence of water vapor.

Origin.—Spinel has been described as an alteration product of corundum and garnet. It is also a primary component of igneous rocks and a product of metamorphism in rocks rich in magnesium.

Uses.—Only the transparent ruby spinels have found a use. These are employed as gems.

Ceylonite, or **pleonaste,** is a spinel in which a portion of the Mg has been replaced by Fe, *i.e.*, is an isomorphous mixture of the magnesian and iron aluminates; thus $((Mg \cdot Fe)(AlO_2)_2)$. It is usually black or green and translucent, and has a brownish or dark greenish streak and a density = 3.5–3.6.

The analysis of a sample separated from an igneous rock in Madison Co., Mont., gave,

Al_2O_3	FeO	MgO	Cr_2O_3	Fe_2O_3	MnO	CaO	SiO_2	Total
62.09	17.56	15.61	2.62	2.10	tr	.16	.55	100.69

Ceylonite occurs in igneous rocks in the Lake Laach region, Germany, and in the Piedmont district, Italy and elsewhere; in metamorphosed limestones at Warwick and Amity, N. Y.; in the limestone blocks enclosed in the lava of Vesuvius; and in dolomite metamorphosed by contact action at Monzoni, Tyrol.

Picotite, or **chrome spinel,** is a variety intermediate between spinel proper and chromite. Its composition may be represented by the formula $(Mg \cdot Fe)((Al \cdot Fe \cdot Cr)O_2)_2$. It occurs only in small crystals in basic igneous rocks and in a few crystalline schists. Density = 4.1.

Magnetite ($Fe(FeO_2)_2$)

Magnetite, the ferrous ferrite, the empirical formula of which is Fe_3O_4, is a heavy, black, magnetic mineral which is utilized as one of the ores of iron.

The pure mineral consists of 72.4 per cent Fe and 27.6 per cent O. Most specimens, however, contain also some Mg and many contain small quantities of Mn or Ti. A selected sample of magnetite from the Elizabeth Mine, Mt. Hope, New Jersey, analyzed as follows:

Fe_2O_3	FeO	SiO_2	TiO_2	Al_2O_3	MgO	CaO	Other	Total
65.26	30.20	1.38	1.09	.55	.10	.68	.73	99.99

Magnetite occurs in crystals that are usually octahedrons or dodecahedrons, or combinations of the two. Other forms are rare. Twins are common. The mineral occurs also as sand and in granular and structureless masses. When the dodecahedron is present, its faces are frequently striated parallel to the edge between ∞O(110) and O(111) (Fig. 98).

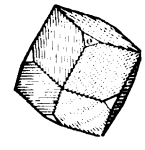


FIG. 98. — Magnetite Crystal, with ∞O (110) and O (111), Showing Striations Parallel to Edge 110 and 111.

Magnetite is black and opaque and its streak is black. It has an uneven or a conchoidal fracture, but no distinct cleavage. Its hardness is 5.5–6 and density 4.9–5.2. It is strongly attracted by a magnet and in many instances it exhibits polar magnetism.

The mineral is infusible before the blowpipe. Its powder dissolves slowly in HCl, and the solution reacts for ferrous and ferric iron.

Magnetite is easily recognized by its color, magnetism, and hardness.

The mineral weathers to limonite and hematite and occasionally to the carbonate, siderite.

Syntheses.—Crystals have been made by cooling iron-bearing silicate solutions; treating heated ferric hydroxide with HCl; and by fusing iron oxide and borax with a reducing flame.

Occurrence and Origin.—The mineral occurs as a constituent of many igneous rocks and crystalline schists, and in lenses embedded in rocks of many kinds. It also constitutes veins cutting these rocks and as irregular masses produced by the dehydration and deoxidation of hematite and limonite under the influence of metamorphic processes. It occurs also as little grains among the decomposition products of iron-bearing silicates, such as olivine and hornblende.

The larger masses are either segregations from igneous magmas or deposits from hot solutions and gases emanating from them.

Localities.—The localities at which magnetite has been found are so numerous that only those of the greatest economic importance may be mentioned here. In Norway and Sweden great segregated deposits are worked as the principal sources of iron in these countries. In the United States large lenses occur in the limestones and siliceous crystalline schists in the Adirondacks, New York, and in the schists and granitic rocks of the Highlands in New Jersey. Great bodies are mined also at Cornwall, and smaller bodies at Cranberry, and in the Far West.

Extraction.—The magnetite is separated from the rock with which it occurs by crushing and exposing to the action of an electro-magnet.

Production.—The total amount of the mineral mined in the United States during 1912 was 2,179,500 tons, of which 1,110,345 tons came from New York, 476,153 tons from Pennsylvania, and 364,673 tons from New Jersey.

Franklinite $((Fe \cdot Zn \cdot Mn)((Fe \cdot Mn)O_2)_2)$

Franklinite resembles magnetite in its general appearance. It is an ore of manganese and zinc.

It differs from magnetite in containing Mn in place of some of the ferric iron in this mineral and Mn and Zn in place of some of its ferrous iron. Since it is an isomorphous mixture of the iron, zinc and manganese salts of the iron and manganese acids of the general formula $R'''O(OH)$, its composition varies within wide limits. The franklinite from Mine Hill, N. J., contains from 39 per cent to 47 per cent Fe, 10 per cent to 19 per cent Mn and 6 per cent to 18 per cent Zn. A specimen from Franklin Furnace, N. J., contained,

Fe_2O_3	MnO	ZnO	MgO	CaO	SiO_2	H_2O	Total
66.58	9.96	20.77	.34	.43	.72	.71	99.51

Its crystals are usually octahedrons, sometimes modified by the dodecahedron and occasionally by other forms. The mineral occurs also in rounded grains, in granular and in structureless masses.

It is black and lustrous and has a dark brown streak. Its fracture and cleavage are the same as for magnetite. It is only very slightly magnetic. It has a hardness of 6 and a density of 5.15.

The mineral is infusible before the blowpipe. When heated on charcoal it becomes magnetic. When fused with Na_2CO_3 in the oxidizing flame it gives the bluish green bead characteristic of manganese. Its fine powder mixed with Na_2CO_3 and heated on charcoal yields the white coating of zinc oxide which turns green when moistened with $Co(NO_3)_2$ solution and again heated.

Franklinite is distinguished from most minerals by its color and crystallization and from *magnetite* and *chromite* by its brown streak and by its reactions for Mn and Zn. It is also characterized by its association with red zincite and green or pink willemite (p. 306).

Synthesis.—Crystals of franklinite have been made by heating a mixture of $FeCl_3$, $ZnCl_2$ and CaO (lime).

Occurrence and Origin.—Franklinite occurs at only a few places. Its most noted localities are Franklin Furnace and Sterling Hill, N. J., where it is associated in a white crystalline limestone with zincite, willemite and other zinc and manganese compounds. The deposit is supposed to have been produced by the replacement of the limestone through the action of magmatic waters and vapors.

Uses.—The mineral is utilized as an ore of manganese and zinc. The ore as mined is crushed and separated into parts, one of which consists largely of franklinite. This is roasted with coal, when the zinc is driven off as zinc oxide. The residue is smelted in a furnace producing spiegeleisen, which is an alloy of iron and manganese used in the manufacture of certain grades of steel.

Production.—The quantity of this residuum produced in 1912 was 104,670 tons, valued at $314,010.

Chromite ($Fe(CrO_2)_2$)

Chromite, or chrome-iron, is the principal ore of chromium. It resembles magnetite and franklinite in appearance. It occurs in isolated crystals, in granular aggregates, and in structureless masses.

Chemically, it is a ferrous salt of metachromous acid, of the theoretical composition $Cr_2O_3 = 68$ per cent and $FeO = 32$ per cent, but it usually contains also small quantities of Al_2O_3, CaO and MgO. An analysis of

a specimen from Chorro Creek, California, after making corrections for the presence of some serpentine, yielded:

Cr_2O_3	Al_2O_3	Fe_2O_3	FeO	MgO	MnO	Total
56.96	12.32	3.81	12.73	14.02	.16	100.00

Its crystals are usually simple octahedrons, but they are not as common as those of the other spinels.

Its color is brownish black and its streak brown. It has a conchoidal or uneven fracture and no distinct cleavage. It is usually nonmagnetic, but some specimens show slight magnetism because of the admixture of the isomorphous magnetite molecule. Its hardness is 5.5 and its density 4.5 to 4.8.

The mineral is infusible before the blowpipe. It gives the chromium reaction with the beads. If its powder is fused with niter and the fusion treated with water, a yellow solution of K_2CrO_4 results. When fused with Na_2CO_3 on charcoal it yields a magnetic residue.

Chromite is easily distinguished from all other minerals but *picotite* by its crystallization and its reaction for chromium. It is distinguished from picotite by its inferior hardness and its higher specific gravity.

Synthesis.—Crystals have been made by fusing the proper constituents with boric acid and after fusion distilling off the boric acid.

Occurrence and Origin.—Chromite occurs principally in olivine rocks and in their alteration product—serpentine. The mineral is found not only as crystals embedded in the rock mass, but also as nodules in it and as veins traversing it. It is probably in all cases a segregation from the magma producing the rock. In a few places the mineral occurs in the form of sand on beaches.

Localities.—It is widely spread through serpentine rocks at many places, notably in Brussa, Asia Minor; at Banat and elsewhere in Norway; at Solnkive, in Rhodesia; in the northern portion of New Caledonia; at various points in Macedonia; in the Urals, Russia; in Beluchistan and Mysore, India.

In the United States the mineral is known at several points in a belt of serpentine on the east side of the Appalachian Mountains, and at many points in the Rocky Mountains, the Sierra Nevada and the Coast Ranges. It has been mined at Bare Hills, Maryland; in Siskiyou, Tehama and Shasta Counties, Colorado; in Converse County, Wyoming; and in Chester and Delaware Counties, Pennsylvania; and, in 1914, some was washed from chrome sand at Baltimore, Maryland.

Metallurgy.—The mineral is mined by the usual methods and concentrated, or, if in large fragments, is crushed. It is then fused with certain oxidizing chemicals and the soluble chromates are produced. Or the ore is reduced with carbon yielding an alloy with iron. The metal is produced by reduction of its oxide by metallic aluminium or by electrolysis of its salts.

Uses.—Chromite is the sole source of the metal chromium, which is the chrome-iron alloy employed in the manufacture of special grades of steel. Chromium salts are used in tanning and as pigments. The crude ore, mixed with coal-tar, kaolin, bauxite, or some other ingredient, is molded into bricks and burned, after which the bricks are used as linings in metallurgical furnaces. These bricks stand rapid changes of temperature and are not attacked by molten metals.

Production.—The annual production of chromite in the world is now about 100,000 tons, of which Rhodesia produces about $\frac{1}{3}$, New Caledonia about $\frac{1}{3}$ and Russia and Turkey about $\frac{1}{6}$ each. The production of the United States in 1912 was 201 tons, valued at $2,753. All came from California. The imports in the same year were 53,929 tons, worth $499,818.

Chrysoberyl ($BeAl_2O_4$)

Chrysoberyl is a beryllium aluminate, the composition of which is analogous to that of the spinels. It may be written $BeO_2(AlO)_2$. Although theoretically it should contain 19.8 per cent BeO and 80.2 per cent Al_2O_3, analyses of nearly all specimens show the presence also of iron and magnesium.

The mineral differs from spinel in crystallizing in the orthorhombic system (bipyramidal class). Its axial ratio is .4707 : 1 : .5823. The principal forms observed on crystals are: P(111), $\infty P\bar{\infty}$ (100), $\infty P\breve{\infty}$ (010), $P\breve{\infty}$ (011), $\infty P\bar{2}$(120) and $2P\bar{2}$(121) (Fig. 99). The crystals are often twins (Fig. 100), trillings or sixlings, with $3P\breve{\infty}$ (031) the twinning plane, forming pseudohexagonal groupings (Fig. 101). Simple crystals are usually tabular parallel to $\infty P\bar{\infty}$ (100), which is striated vertically. Consequently, in twins this face exhibits striations arranged feather-like. The angle $110 \wedge 1\bar{1}0 = 50° 21'$.

The cleavage of chrysoberyl is distinct parallel to $P\breve{\infty}$ (011), and indistinct parallel to $\infty P\breve{\infty}$ (010) and $\infty P\bar{\infty}$ (100). Its fracture is uneven or conchoidal. Its color is some shade of light green or yellow by reflected light. It is transparent or translucent and in some cases is distinctly red by transmitted light. It is strongly pleochroic in orange,

green and red tints. The mineral is brittle, has a hardness of 8.5 and a density of about 3.6. Its refractive indices are: $\alpha = 1.7470$, $\beta = 1.7484$, $\gamma = 1.7565$.

Four distinct varieties are recognized:

Ordinary, pale green, translucent.

Gem, yellow and transparent.

Alexandrite, emerald-green in color, but red by transmitted light, transparent, usually in twins. Used as a gem.

Cat's-eye, a greenish variety exhibiting a play of colors (chatoyancy).

Before the blowpipe the mineral is infusible. It yields the Al reaction with $Co(NO_3)_2$, but otherwise is only slightly affected by the flame. It is insoluble in acids.

Chrysoberyl is characterized by its crystallization and great hard-

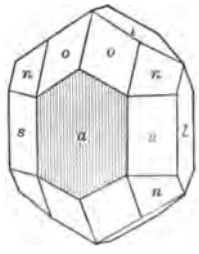


FIG. 99.

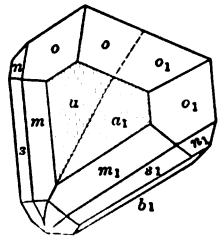


FIG. 100.

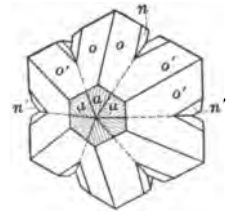


FIG. 101.

FIG. 99.—Chrysoberyl Crystal with $\infty P \breve{\infty}$, 100 (*a*); $\infty P \breve{\infty}$, 010 (*b*); $\infty P \breve{2}$, 120 (*s*); $2P \breve{2}$, 121 (*n*); P, 111 (*o*) and $P \breve{\infty}$, 011 (*i*).

FIG. 100.—Chrysoberyl Twinned about $3P \breve{\infty}$ (031).

FIG. 101.—Chrysoberyl Pseudohexagonal Sixling Twinned about $3P \breve{\infty}$ (031).

ness. It most closely resembles the beryllium silicate, *beryl*, in appearance, but is easily distinguished from this by its crystallization.

Synthesis.—Crystals have been made by fusing BeO and Al_2O_3 with boric acid and then distilling off the boric acid.

Occurrence and Origin.—Chrysoberyl is found principally in granites and crystalline schists and as grains in the sands produced by the erosion of these rocks. In its original position the mineral is a separation from the magma that produced the rocks.

Localities.—Its best known localities are in Minas Geraes, Brazil; near Ekaterinburg, Ural; in the Mourne Mts., Ireland; at Haddam, Conn.; at Greenfield, N. Y.; at Orange Summit, N. Hamp.; and at Norway and Stoneham, Me. The alexandrite comes from Ceylon, where it occurs as pebbles, and from the Urals.

Braunite ($MnMnO_3$) occurs massive and in crystals. The latter are tetragonal (ditetragonal bipyramidal class), with $a : c = 1 : .9922$. They are usually simple bipyramids P(111). Because of the nearly equal value of a and c all crystals are isometric in habit. The angle $111 \wedge 1\bar{1}1 : 70° 7'$. Twins are common, with P∞(101) the twinning plane. Cleavage is perfect parallel to P(111).

The mineral is brownish black to steel-gray in color and in streak. Its luster is submetallic. Its hardness is 6–6.5 and density 4.7. It is infusible before the blowpipe. With fluxes it gives the usual reactions for manganese. It is soluble in HCl yielding chlorine.

It occurs in veins with manganese and other ores in Piedmont, Italy, and at Pajsberg and various other places in Sweden, where its origin is secondary.

Hausmannite (Mn_2MnO_4) crystallizes like braunite, but $a : c = 1 : 1.1573$ and its crystals are, therefore, distinctly tetragonal in habit. They are usually simply P(111) or combinations of P(111) and $\frac{1}{3}$P(113), though much more complicated crystals are known. The angle $111 \wedge 1\bar{1}1 = 60° 1'$. Twins and fourlings (Fig. 102) are common, with

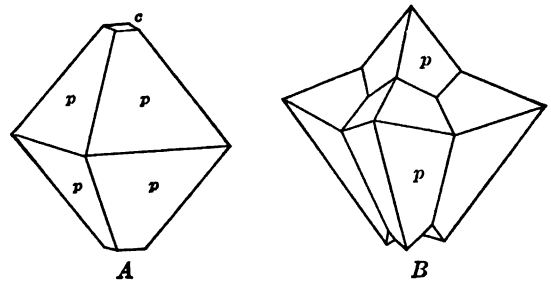


FIG. 102.—Hausmannite. (A) Simple Crystal, P, 111 (p) and oP, 001 (c). (B) Fiveling Twinned about P∞(101).

P∞(101) the twinning plane. The cleavage is imperfect parallel to oP(001). The mineral also occurs in granular masses.

Hausmannite is brownish black. Its streak is chestnut brown. Its hardness is 5–5.5 and density 4.8. Its reactions are the same as those of braunite.

Hausmannite occurs as crystals at Ilmenau, Thüringia; Ilfeld, Harz, and as granular masses in dolomite at Nordmark and several other points in Sweden. Like braunite it is probably a decomposition product of other manganese minerals.

CHAPTER X

THE NITRATES AND BORATES

THE NITRATES

THE nitrates are salts of nitric acid. Only two are of importance to us, *saltpeter* (KNO_3) and *chile saltpeter* ($NaNO_3$). Both are colorless, or white, crystalline bodies, both are soluble in water and both produce a cooling taste when applied to the tongue. The potassium compound is distinguished from the sodium compound by the flame test. Both minerals when heated in the closed tube with $KHSO_4$ yield red vapors of nitrogen peroxide (NO_2).

Soda Niter ($NaNO_3$)

Soda niter, or chile saltpeter, is usually in incrustations on mineral surfaces or in massive forms. It consists of 63.5 per cent N_2O_5 and 36.5 per cent Na_2O.

Its crystals are in the ditrigonal scalenohedral class of the hexagonal system with an axial ratio of $a : c = 1 : .8297$. They are usually rhombohedrous $R(10\bar{1}1)$ in some cases modified by $oR(0001)$. Apparently the mineral is completely isomorphous with calcite ($CaCO_3$).

Its cleavage is perfect parallel to the rhombohedron. Its hardness is under 2, its density about 2.27 and its melting point about 312°. Its luster is vitreous; color white, or brown, gray or yellow. The mineral is transparent. Its refractive indices for yellow light are: $\omega = 1.5854$, $\epsilon = 1.3369$.

Soda niter deflagrates when heated on charcoal and colors the flame yellow. When exposed to the air it attracts moisture and finally liquefies. It is completely soluble in three times its own weight of water.

Occurrence and Localities.—The principal occurrences of the mineral are in the district of Tarapaca, northern Chile, where, mixed with the iodate and other salts of sodium and potassium, under the name *caliche*, it comprises beds several feet thick on the surface of rainless pampas, and in Bolivia at Arane under the same conditions. It is associated with gypsum, salt and other soluble minerals. Smaller

deposits are found in Humboldt Co., Nevada, in San Bernardino Co., Cal., and in southern New Mexico.

The material is thought to result from the action of microorganisms upon organic matter decomposing in the presence of abundant air.

Uses.—Soda niter is used in the production of nitric acid, and in the manufacture of fertilizers and gunpowder. About 480,000 tons are imported into the United States annually at a cost of $15,430,000. Most of it comes from Chile.

Since soda niter usually contains sodium iodate as an impurity, the mineral is an important source of iodine.

Niter (KNO_3)

Niter, or saltpeter, resembles soda niter in appearance. It generally occurs in crusts, in silky tufts and in groups of acicular crystals. Its crystals are orthorhombic with $a : b : c = .5910 : 1 : .7011$. Their habit is hexagonal. The principal forms observed on them are $\infty P(110)$, $\infty P\bar{\infty}(100)$, $\infty P\breve{\infty}(010)$, $oP(001)$, $P(111)$, and a series of brachydomes. In many respects the mineral is apparently isomorphous with aragonite which is the orthorhombic dimorph of calcite. At 126° it passes over into an hexagonal (trigonal) form. Its cleavage is perfect parallel to $P\breve{\infty}(011)$. Its fracture is uneven; its hardness 2 and density 2.1. Its medium refractive index for yellow light, $\beta = 1.5056$.

Niter deflagrates more violently than soda niter and detonates with combustible substances. It fuses at about 335°. It colors the blowpipe flame violet. It is soluble in water.

Occurrence and Localities.—The mineral forms abundantly in dry soils in Spain, Egypt, Persia, Ceylon and India, where it is produced by a ferment, and on the bottoms of caves in the limestones of Madison Co., Ky., of Tennessee, of the valley of Virginia and of the Mississippi Valley.

Production.—Most of the niter used in the arts is manufactured, but some is obtained from the deposits in Ceylon and in India. The amount imported in 1912 aggregated 6,976,000 lb., valued at $226,851.

THE BORATES

The borates are salts of boric acid, H_3BO_3, metaboric acid, HBO_2, tetraboric acid, $H_2B_4O_7$, hexaboric acid, $H_4B_6O_{11}$, and various polyboric acids in which boron is present in still larger proportion. The metaacid is obtained from the orthoacid by heating at 100°, at which

temperature the former loses one molecule of water, thus: $H_3BO_3 - H_2O = HBO_2$, and the tetraacid by heating the same compound to 160° at which temperature 5 molecules of water are lost from 4 molecules of the acid, thus: $4H_3BO_3 - 5H_2O = H_2B_4O_7$. Hexaboric acid may be regarded as the orthoacid less $1\frac{1}{6}$ molecules of water, thus: $6H_3BO_3 - 7H_2O = H_4B_6O_{11}$.

Only three of the borates are important enough to be discussed here. These are *borax*, a sodium tetraborate ($Na_2B_4O_7 \cdot 10H_2O$), *colemanite*, a hexaborate ($Ca_2B_6O_{11} \cdot 5H_2O$) and *boracite*, a magnesium chloro-polyborate ($Mg_5(MgCl)_2B_{16}O_{30}$). Borax and colemanite are commercial substances that are produced in large quantities.

All borates and many other compounds containing boron when pulverized and moistened with H_2SO_4 impart an intense yellow-green color to the flame. If boron compounds are dissolved in hydrochloric acid, the solution will turn turmeric paper reddish brown after drying at 100°. The color changes to black when the stain is treated with ammonia.

Borax ($Na_2B_4O_7 \cdot 10H_2O$)

Borax occurs as crystals and as a crystalline cement between sand grains around salt lakes, as an incrustation on the surfaces of marshes and on the sands in desert regions, and dissolved in the water of certain lakes in deserts. It occurs also as bedded deposits interlayered with sedimentary rocks.

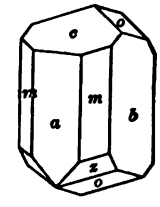


FIG. 103.—Borax Crystal with ∞P, 110 (*m*); ∞P$\bar{\infty}$, 100 (*a*); ∞P$\breve{\infty}$, 010 (*b*); oP, 001 (*c*); P, $\bar{1}11$ (*o*) and 2P, $\bar{2}21$ (*z*).

The composition of borax is 16.2 per cent Na_2O, 36.6 per cent B_2O_3 and 47.2 per cent H_2O.

Crystals are monoclinic (prismatic class), with $a : b : c = 1.0995 : 1 : .5629$, and $\beta = 73° 25'$. They are prismatic in habit and in general form resemble very closely crystals of pyroxene. The principal planes occurring on them are ∞P$\bar{\infty}$ (100), ∞P(110), oP(001), −P(111) and −2P(221) (Fig. 103). Their cleavage is perfect parallel to ∞P$\bar{\infty}$ (100), and their fracture conchoidal. The angle $110 \wedge 1\bar{1}0 = 93°$.

The mineral has a white, grayish or bluish color and a white streak. It is brittle, vitreous, resinous or earthy; is translucent or opaque; has a hardness of 2–2.5, a density of 1.69–1.72, and a sweetish alkaline taste. On exposure to the air the mineral loses water and tends to become white

and opaque, whatever its color in the fresh condition. Its medium refractive index for yellow light, $\beta = 1.4686$.

Before the blowpipe borax puffs up and fuses to a transparent globule. Fused with fluorite and potassium bisulphate it colors the flame green. It is soluble in water, yielding a weakly alkaline solution.

Occurrence.—The principal method of occurrence of the mineral is as a deposit from salt lakes in arid regions, and as incrustations on the surfaces of alkaline marshes overlying buried borax deposits. The original beds were deposited by the evaporation to dryness of ancient salt lakes, and the incrustations were produced by the solution of these deposits by ground water, and the rise of the solutions to the surface by capillarity.

Localities.—Borax occurs in the water of salt lakes in Tibet; of several small lakes in Lake County, and of Borax Lake in San Bernardino County in California, and in the mud and marshes around their borders. It occurs also in the sands of Death Valley in the same State, and in various marshes in Esmeralda County, Nevada. Other large deposits are found in Chile and Peru.

Uses.—Borax is used as an antiseptic, in medicine, in the arts for soldering brass and welding metals, and in the manufacture of cosmetics. Boric acid obtained from borax and colemanite is employed in the manufacture of colored glazes, in making enamels and glass, as an antiseptic and a preservative. Some of the borates are used as pigments.

Production.—Borax was formerly obtained in the United States, especially in California, Oregon and Nevada, by the evaporation of the water of borax lakes, by washing the crystals from the mud on their bottoms and by the leaching of the mineral from marsh soil. At present, however, nearly all the borax of commerce is manufactured from colemanite.

Colemanite ($Ca_2B_6O_{11} \cdot 5H_2O$)

Colemanite occurs in crystals and in granular and compact masses. It is the source of all the borax now manufactured in the United States.

The formula ascribed to the mineral corresponds to 27.2 per cent CaO, 50.9 per cent B_2O_3 and 21.9 per cent H_2O. As usually found, however, it contains a little MgO and SiO_2. A crystal from Death Valley, California, yielded:

$B_2O_3 = 50.70$; $CaO = 27.31$; $MgO = .10$; $H_2O = 21.87$. Total $= 99.98$.

The mineral crystallizes in the monoclinic system (prismatic class), in short, prismatic crystals (Fig. 104), with the axial constants $a : b : c = .7769 : 1 : .5416$ and $\beta = 69° 43'$. The crystals are usually rich in forms. Their cleavage is perfect parallel to $\infty O \breve{\infty}$ (010), and less perfect parallel to oP(001). Their fracture is uneven. The angle $110 \wedge 1\bar{1}0 = 72° 4'$.

Colemanite is colorless, milky white, yellowish white or gray. It is transparent or translucent, has a vitreous or adamantine luster, a hardness of 4 to 4.5 and a specific gravity of 2.4. Its index of refraction for yellow light, $\beta = 1.5920$.

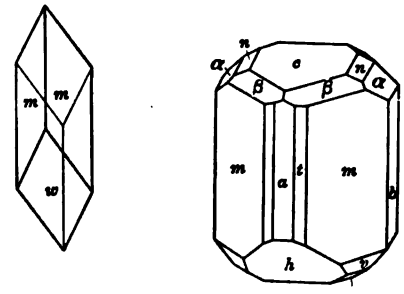


FIG. 104.—Colemanite Crystals with ∞P, 110 (*m*); $3P\bar{\infty}$, $\bar{3}01$ (*w*); $\infty P\bar{\infty}$, 100 (*a*); $\infty P\breve{\infty}$, 010 (*b*); oP, 001 (*c*); $-P$, 111 (β); $2P\breve{\infty}$, 021 (α); $P\breve{\infty}$, 011 (κ); $\infty P\bar{2}$, 210 (*t*); $2P\bar{\infty}$, $\bar{2}01$ (*h*); 2P, $\bar{2}21$ (*v*) and P, $\bar{1}11$ (*y*).

Before the blowpipe it decrepitates, exfoliates, and partially fuses, at the same time coloring the flame yellowish green. It is soluble in hot HCl, but from the solution upon cooling a voluminous mass of boric acid separates as a white gelatinous precipitate.

It is easily distinguished from other white translucent minerals, except those containing boron, by the flame test. It is distinguished from *borax* by its insolubility in water and from *boracite* by its inferior hardness and crystallization.

Synthesis.—Colemanite has been prepared by treating ulexite ($NaCaB_5O_9 \cdot 8H_2O$) with a saturated solution of NaCl at 70°.

Occurrence and Origin.—The mineral occurs as indefinite layers interstratified with shale and limestones that are associated with basalt. The rocks contain layers and nodules of colemanite. Gypsum is often associated with the borate and in some places is in excess. The colemanite is believed to be the result of the action of emanations from the basalt upon the limestone.

Localities.—Colemanite occurs in Death Valley, California, near Daggett, San Bernardino County, and near Lang Station, Los Angeles County, and at other points in the same State, and in western Nevada, near Death Valley. A snow-white, chalky variety (*priceite*) has been found in Curry County, Oregon, and a compact nodular variety (*pandermite*) at the Sea of Marmora, and at various points in Asia Minor.

Preparation.—Colemanite is at the present time the principal source

of borax. The crude material as mined contains from 5 per cent to 35 per cent of anhydrous boric acid (B_2O_3). This is crushed and roasted. The colemanite breaks into a white powder which is separated from pieces of rock and other impurities by screening, and then is bagged and shipped to the refineries where it is manufactured into borax and boracic acid.

Production.—The principal mines producing the mineral in 1912 were situated in the Death Valley section of Inyo County, near Lang Station in Los Angeles County, California, and in Ventura County in the same State. The total production during the year was 42,315 tons of crude ore, valued at $1,127,813. The imports of crude ore, refined borax and boric acid during the same year were valued at $11,200. The production of the United States in boron acid compounds is about half that of the entire world, with Chile producing nearly all the rest.

Boracite ($Mg_5(MgCl)_2B_{16}O_{30}$)

Boracite is interesting as a mineral, the form and internal structure of which do not correspond, that is, do not possess the same symmetry. Its crystals have the well marked hextetrahedral symmetry of the isometric system, but their internal structure, as revealed by their optical properties is orthorhombic. This is due to the fact that the substance is dimorphous. Above 265° it is isometric and below that temperature orthorhombic. Crystals formed at temperatures above 265° assume the isometric shapes. As the temperature falls the substance changes to its orthorhombic form, and there results a pseudomorph of orthorhombic boracite after its isometric dimorph.

It is a salt of the acid which may be regarded as related to boric acid as follows: $8H_3BO_3 - 9H_2O = H_6B_8O_{15}$. Ten atoms of hydrogen in two molecules of the acid are replaced by Mg_5 and the other two by $2(MgCl)$. The resulting combination is: 31.4 per cent MgO; 7.9 per cent Cl and 62.5 per cent $B_2O_3 = 101.8(O = Cl = 1.9)$. The mineral alters slowly, taking up water, so that some specimens yield water on analysis and in the closed tube (*stassfurtite* and *parasite*).

The forms usually found on the crystals are $\frac{O}{2}(111)$, $\infty O(110)$, $\infty O \infty (100)$, $-\frac{O}{2}(1\bar{1}1)$ (Fig. 105). Usually the positive and negative tetrahedrons may be distinguished by their luster, the faces of the positive form being brilliant and those of the negative form dull. The crystals are isolated, or embedded, and rarely in groups. They are

strongly pyroelectric with the analogue pole in the negative tetrahedrons. The mineral is also found massive.

Boracite is transparent or translucent and is gray, yellow, or green. Its streak is white. Its luster is vitreous. Its cleavage is indistinct parallel to O(111) and its fracture is conchoidal. The mineral is brittle. Its hardness is 7 and its density 3. Its refractive index β, for yellow light, $=1.667$.

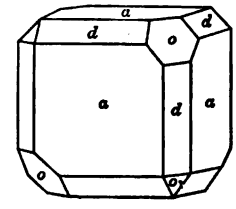


FIG. 105. — Boracite Crystal with $\infty O \infty$, 100 (*a*); ∞O, 110 (*d*); $+\frac{O}{2}$, 111 (*o*) and $-\frac{O}{2}$, $1\bar{1}1$ (o_1).

Boracite fuses easily before the blowpipe with intumescence to a white pearly mass, at the same time coloring the flame green. With copper oxides it colors the flame azure-blue. When moistened with $Co(NO_3)_2$ it gives the pink reaction for magnesium. Some massive forms yield water in the closed tube, in consequence of weathering. The mineral is soluble in HCl.

Boracite is distinguished from other boron salts by its crystallization, its lack of cleavage and its much greater hardness. The massive varieties which resemble fine-grained white *marble* can be distinguished from this by the flame coloration, hardness and reaction with HCl.

Syntheses.—Crystals have been formed by heating borax, $MgCl_2$ and a little water at 275°, and by fusing borax with a mixture of NaCl and $MgCl_2$.

Occurrence.—Boracite occurs in beds with anhydrite, gypsum and salt, and as crystals in metamorphosed limestones.

Localities.—It is found as crystals in gypsum and anhydrite at Lüneburg, Hanover, and Segeberg, Holstein; in carnallite at Stassfurt, Prussia; and in radiating nodules (stassfurtite) and in massive layers associated with salt beds at the last-named locality. It is rare in the United States.

Uses and Production.—Boracite is utilized in Europe as a source of boron compounds. Turkey produces annually about 12,000 tons.

CHAPTER XI

THE CARBONATES

THE carbonates constitute an important, though not a very large, group of minerals, though one of them, calcite, is among the most common of all minerals. They are all salts of carbonic acid (H_2CO_3). Those in which all the hydrogen has been replaced by metal are normal salts, those in which the replacement has been by a metal and a hydroxyl group are basic salts. Both groups are represented by common minerals.

The normal salts include both anhydrous salts and salts combined with water of crystallization. Illustrations of the three classes of carbonates are: $CaCO_3$, *calcite*, normal salt; $Na_2CO_3 \cdot 10H_2O$, *soda*, hydrous salt and $(Cu \cdot OH)_2CO_3$, *malachite*, basic salt. All carbonates effervesce in hot acids. The basic salts yield water at a high temperature only; the hydrous ones at a low temperature.

The carbonates are all transparent or translucent, and all are poor conductors of electricity. Most of them are practically nonconductors.

ANHYDROUS CARBONATES

NORMAL CARBONATES

The anhydrous normal carbonates comprise the most important carbonates that occur as minerals. Most of them are included in a single large group whose members are dimorphous, crystallizing in the ditrigonal scalenohedral class of the hexagonal system and in the holohedral division (rhombic bipyramidal class) of the orthorhombic system. The calcium carbonate exists in three forms but only two are known to occur as minerals.

CALCITE-ARAGONITE GROUP

The relation of the dimorphs of this group to one another has been subjected to much study, especially with reference to the two forms of $CaCO_3$. The orthorhombic form, *aragonite*, passes into the hexagonal form, *calcite*, upon heating to about 400°. At all temperatures below 970°, calcite is the stable form. Moreover, while calcite crystallizes from a dilute solution of $CaCO_3$ in water containing CO_2 at a low tem-

perature, aragonite separates at a temperature approaching that of boiling water—the more freely, the less CO_2 in the solution. Aragonite crystals will also separate from a solution of calcium carbonate, if, at the same time, it contains a grain of an orthorhombic carbonate, or a small quantity of a soluble sulphate. Some of the other carbonates, for instance, strontianite (the orthorhombic $SrCO_3$), pass over into an hexagonal form like that of calcite at 700°, but again change to the orthorhombic form upon cooling. For convenience the group is divided for discussion into the calcite division and the aragonite division.

CALCITE DIVISION

The calcite division of carbonates includes nine or more distinct compounds and a number of well defined varieties of these. Six of the compounds are common minerals. All crystallize in the ditrigonal scalenohedral class of the hexagonal system and are thus isomorphous. Their most common crystals have a rhombohedral habit. The names of the six common members with their axial ratios are:

Calcite	$CaCO_3$	$a : c = 1 : .8543$
Magnesite	$MgCO_3$	$= 1 : .8095$
Siderite	$FeCO_3$	$= 1 : .8191$
Rhodochrosite	$MnCO_3$	$= 1 : .8259$
Smithsonite	$ZnCO_3$	$= 1 : .8062$

There is usually also included in the group the mineral *dolomite*, which is a calcium magnesium carbonate in which $CaCO_3$ and $MgCO_3$ are present in the molecular proportions, thus: $MgCO_3 \cdot CaCO_3$, or $MgCa(CO_3)_2$. Its crystals are similar to those of calcite and its physical properties are intermediate between those of calcite and magnesite. Its symmetry, however, as revealed by etching is tetartohedral (rhombohedral class).

The close relationship existing between the members of the group (including dolomite) will be appreciated upon comparing the data in the following table:

	H	Sp. Gr.	$a : c$	$10\bar{1}1 \wedge 01\bar{1}1$	Ref. Indices ω	ϵ
Calcite.....	3.	2.73	.8543	74° 55′	1.6585	1.4863
Dolomite.....	3.5–4	2.85	.8322	73° 45′	1.6817	1.5026
Magnesite.....	3.5–4.5	3.04	.8095	72° 36′	1.717	1.515
Siderite.....	3.5–4	3.88	.8191	73° 0′	1.8724	1.6338
Rhodochrosite..	3.5–4.5	3.55	.8259	73° 0′	1.820	1.5973
Smithsonite....	5.	4.45	.8062	72° 20′	1.818±	1.6177

Calcite ($CaCO_3$)

Calcite is one of the most beautifully crystallized minerals known. Its crystals are very common, and sometimes very large. They are usually colorless, though sometimes colored, and are nearly always transparent. Besides occurring in crystals the mineral is often found massive, in granular aggregates, in stalactites, in pulverulent masses,

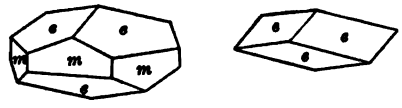


FIG. 106.

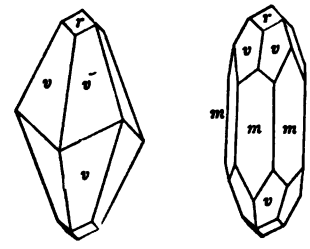


FIG. 108.

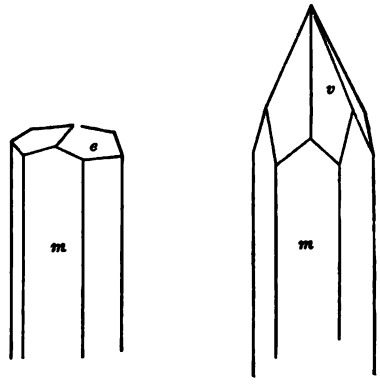


FIG. 107.

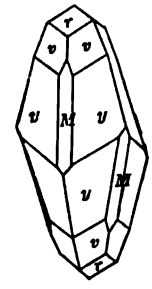


FIG. 109.

FIG. 106.—Calcite Crystal with $-\frac{1}{2}R$, $01\bar{1}2$ (*e*) and ∞R, $10\bar{1}0$ (*m*). Nail-head Spar.
FIG. 107.—Calcite Crystal with *m* and *e*. Prismatic Type.
FIG. 108.—Calcite Crystals with *m*; R^3, $21\bar{3}1$ (*v*) and *R*, $10\bar{1}1$ (*r*). Dog-tooth Spar.
FIG. 109.—Calcite with *r*, *v*; 4R, $40\bar{4}1$ (*M*) and R^5, $32\bar{5}1$ (*y*).

in radial groupings, in fibrous masses and in a variety of other forms. As calcite is soluble in water containing CO_2, it has often been found pseudomorphing other minerals.

Theoretically, calcite contains 56 per cent CaO and 44 per cent CO_2, but practically the mineral contains also small quantities of Mg, Fe, Mn, Zn and Pb, metals whose carbonates are isomorphous with $CaCO_3$.

The forms that have been observed on calcite crystals are arranged

in such a manner as to produce three distinct types of habit, as follows: (1) the rhombohedral type, bounded by the flat rhombohedrons, $R(10\bar{1}1)$, $-\frac{1}{2}R(01\bar{1}2)$ and often blunt scalenohedrons, like $R^3(21\bar{3}1)$ and $\frac{2}{5}R^2(31\bar{4}5)$ in which the rhombohedrons predominate (Fig. 106); (2) the prismatic type, with the prism $\infty P(10\bar{1}0)$ predominating, and $-\frac{1}{2}R(01\bar{1}2)$ as the principal termination (Fig. 107), and (3) dog-tooth spar, containing the same scalenohedrons as on the first type mentioned above with other steeper ones and small steep rhombohedral planes (Fig. 108, 109, 110). Nail-head spar contains the flat rhombohedron $-\frac{1}{2}R(01\bar{1}2)$ with the prism $\infty P(10\bar{1}0)$ (Fig. 106).

FIG. 110.—Prismatic Crystals of Calcite Terminated by Scalenohedrons and Rhombohedrons, from Cumberland, England.

Some of the crystals are very complicated, belonging to no one of the distinct types described above, but forming barrel-shaped or almost round bodies. Over 300 well established forms have been identified on them.

Twins are common. The principal laws are: (1) twinning plane $oP(0001)$, with the vertical axis common to the twinned parts (Fig. 111), (2) twinning plane $-\frac{1}{2}R(01\bar{1}2)$, with the two vertical axes inclined

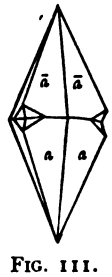


FIG. 111.

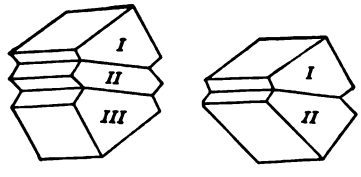


FIG. 112.

FIG. 111.—Calcite, R^2 $(21\bar{3}1)$ Twinned about oP (0001).

FIG. 112.—Calcite: Twin and Polysynthetic Trilling of R $(10\bar{1}1)$ about $-\frac{1}{2}R$ $(01\bar{1}2)$.

at an angle of about $52\frac{1}{2}°$ (Fig. 112) and (3) twinning plane $R(10\bar{1}1)$, with the vertical axes inclined 89° 14′ (Fig. 113).

Twins of the second class can easily be produced artificially on cleavage rhombs by pressing a dull knife edge on the obtuse rhombohedral edge with sufficient force to move a portion of the mass (Fig. 114). The change of position of a portion of the calcite does not destroy its

transparency in the least. Repeated twinning of this kind is frequently seen in marble (Fig. 115), where it gives rise to parallel lamellae.

The cleavage of calcite is so perfect parallel to R that crystals when

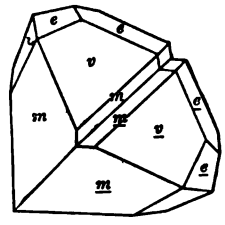


FIG. 113.

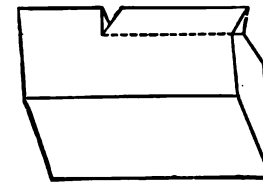


FIG. 114.

FIG. 113.—Calcite with *m*, *v* and *e*, Twinned about *R* ($10\bar{1}1$).

FIG. 114.—Artificial Twin of Calcite, with $-\frac{1}{2}R$ ($01\bar{1}2$) the Twinning Plane.

shattered by a hammer blow usually break into perfect little rhombohedrons. Its hardness is about 3 and its density 2.713. Pure calcite is colorless and transparent, but most specimens are white or some pale shade of red, green, gray, blue, yellow, or even brown or black when very impure, and are translucent or opaque. The mineral is very strongly doubly refracting, (see p. 213). It is a very poor conductor of electricity.

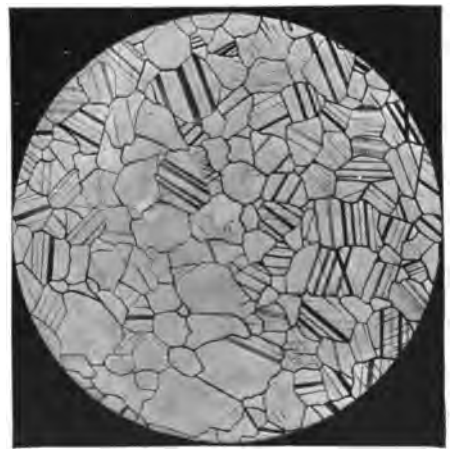


FIG. 115.—Thin Section of Marble Viewed by Polarized Light. The dark bars are polysynthetic twinning lamellae. Magnified 5 diameters.

The principal varieties of the mineral to which distinct names have been given are:

Iceland spar, the transparent variety used in the manufacture of optical instruments.

Satin spar, a fine, fibrous variety with a satiny luster.

Limestone, granular aggregates occurring as rock masses.

Marble, a crystalline limestone, showing when broken the cleavage faces of the individual crystals.

Lithographic stone, a very fine and even-grained limestone.

Stalactites, cylinders or cones of calcite that hang from the roofs of caves. They are formed by the evaporation of dripping water.

Stalagmites, corresponding cones on the floors of caves beneath the stalactites.

Mexican onyx, banded crystalline calcite, often transparent. Usually portions of stalactites.

Travertine, a deposit of white or yellow porous calcite produced in springs or rivers, often around organic material like the blades or roots of grass.

Chalk, a fine-grained, pulverulent mass of calcite, occurring in large beds.

In the closed tube calcite often decrepitates. Before the blowpipe it is infusible. It colors the flame reddish yellow and after heating reacts alkaline toward moistened litmus paper. The mineral dissolves with evolution of CO_2 in cold hydrochloric acid. Its dissociation temperature [1] is 898°, though it begins to lose CO_2 at a much lower temperature.

The reaction with HCl, together with the alkalinity of the mineral after heating, its softness and its easy cleavage, distinguish calcite from all other minerals. In massive forms it has been thought that it could be distinguished from aragonite by heating its powder with a little $Co(NO_3)_2$ solution. Aragonite was thought to become violet-colored in a few minutes while calcite remained unchanged, but recent work proves that this test cannot be relied upon.

Syntheses.—Calcite crystals are obtained by allowing a solution of $CaCO_3$ in dilute carbonic acid to evaporate slowly in contact with the air at ordinary temperatures. If evaporated at from 80° to 100° ordinary temperatures, or in the presence of a little sulphate, the orthorhombic aragonite will form. Calcite is also formed by heating aragonite to 400–470°.

Occurrence and Origin.—The mineral is widely distributed in beds, in veins and as loose deposits on the bottoms of springs, lakes and rivers. Its principal methods of origin are precipitation from solutions, the weathering of calcareous minerals, and secretion by organisms.

Calcite is the most important of all pseudomorphing agencies. It forms pseudomorphs after many different minerals and the hard parts of animals.

Localities.—The most noted localities of crystallized calcite are: Andreasberg in the Harz; Freiberg, Schneeberg and other places in Saxony; Kapnik, in Hungary; Traversella, in Piedmont; Alston Moor

[1] The dissociation temperature of a carbonate is that temperature at which the pressure of the released CO_2 equals one atmosphere.

and Egremont, in Cumberland, Matlock, in Derbyshire, and the mines of Cornwall, England; Guanajuato, Mexico; Lockport, N. Y.; Keweenaw Point, Mich.; the zinc regions of Illinois, Wisconsin and Missouri; Nova Scotia, etc.

Iceland spar is obtained in the Eskefjord and the Breitifjord in Iceland. Travertine is deposited from the waters of the Mammoth Hot Springs, Yellowstone National Park. It occurs also along the River Arno, near Tivoli, Rome.

Uses.—Calcite has many important uses. In the form of Iceland spar, on account of its strong double refraction, it is employed in optical instruments for the production of polarized light. Calcite rocks are used as building and ornamental stones. They are employed also as fluxes in smelting operations, as one of the ingredients in glass-making and in the manufacture of lime, cement, whiting, and in certain printing operations. Limestone is also used as a fertilizer.

Production.—The calcite rock marketed in the United States during 1912 was valued at about $44,500,000. It was used as follows: In concrete, $5,634,000; in road and railroad making, $12,000,000; as a flux, $10,000,000; as building and monumental stone, $12,800,000; in sugar factories, $335,000; as riprap, $1,183,000, for paving, $279,000, and for other uses, $2,400,000. Moreover, the value of the Portland cement manufactured during the year amounted to $67,017,000, the quantity of lime made to $13,970,000, the value of the hydrated lime to $1,830,000, and of sand-lime brick to $1,170,884. The quantity of limestone required for these manufactures is not known, but it was very great.

Magnesite ($MgCO_3$)

Magnesite usually occurs in fine-grained white masses. Crystals are rare. Pure magnesite consists of 52.4 per cent CO_2 and 47.6 per cent MgO. It usually, however, contains some iron carbonate.

Magnesite is completely isomorphous with calcite. Its cleavage is perfect parallel to $R(10\bar{1}1)$. Its hardness is about 4 and the density 3.1.

The mineral is transparent or opaque. It varies in color from white to brown, but always has a white streak. Its dissociation temperature is 445°.

Magnesite behaves like calcite before the blowpipe. It effervesces in hot hydrochloric acid and readily yields the reaction for magnesia with $Co(NO_3)_2$. It is most easily distinguished from the latter mineral by its density, by the fact that it does not color the blowpipe flame with the yellowish red tint of calcium and does not effervesce in cold HCl.

Synthesis.—Magnesite crystals may be obtained by heating $MgSO_4$ in a solution of Na_2CO_3 at 160° in a closed tube.

Occurrence and Origin.—Magnesite usually occurs in veins and masses associated with serpentine and other magnesium rocks from which it has been formed by decomposition. It is often accompanied by brucite, talc, dolomite and other magnesium compounds. It has recently been described as occurring also in a distinct bed near Mohave, Cal., interstratified with clays and shales. It is thought that in this case it may have been precipitated from solutions of magnesium salts by Na_2CO_3.

Localities.—The mineral is found abundantly in many foreign localities and at Bolton, Mass.; Bare Hills, near Baltimore, Md., and in Tulare Co., Cal., and near Texas, Penn. The largest deposits are in Greece and Hungary.

Uses.—Magnesite is employed very largely in the manufacture of magnesite bricks used for lining converters in steel works, in the lining of kilns, etc., in the manufacture of paper from wood pulp, and in making artificial marble, tile, etc. From it are also manufactured epsom salts, magnesia (the medicinal preparation), and other magnesium compounds, and the carbon dioxide used in making soda water.

Production.—All of the magnesite mined in the United States comes from California, where the yield was 10,512 tons in 1912, valued at $105,120. Most of the magnesite used in the United States is imported from Hungary and Greece. In 1912, 14,707 tons of crude material entered the country and 125,000 tons of the calcined product, the total value of which was $1,370,000.

Siderite ($FeCO_3$)

Siderite is an important iron ore, though not as much used as formerly. It is found crystallized and massive, in botryoidal and globular forms and in earthy masses.

In composition the mineral is $FeCO_3$, which is equivalent to 62.1 per cent FeO (48.2 per cent Fe) and 37.9 per cent CO_2. Manganese, calcite and magnesium are also often present in it.

Crystals are more common than those of magnesite. They frequently contain the basal plane and the steep rhombohedrons $-8R(08\bar{8}1)$ and $-5R(05\bar{5}1)$. $R(10\bar{1}1)$ and $-\frac{1}{2}R(01\bar{1}2)$ are common. The faces of the rhombohedron are frequently curved. Compare (Fig. 125.)

The cleavage of siderite is like that of the other minerals of this group. Its hardness is 3.5–4 and density 3.85. In color the mineral is sometimes white, but more frequently it is some shade of yellow or brown. Its streak is white. Most specimens are translucent.

In the closed tube siderite decrepitates, blackens and becomes magnetic. It is only slowly affected by cold acids but it effervesces briskly in hot ones.

Siderite is distinguished from the other carbonates by its reaction for iron.

The mineral changes on exposure into limonite and sometimes into hematite or even into magnetite.

Synthesis.—Crystals of siderite may be obtained by heating a solution of $FeSO_4$ with an excess of $CaCO_3$ at 200°.

Occurrence and Origin.—The mineral is often found accompanying metallic ores in veins. It occurs also as nodules in certain clays and in the coal measures. In some cases it appears to be a direct deposit from solutions. In others it is a result of metasomatism and in others is an ordinary weathering product.

Localities.—The crystallized variety is found at Freiberg, in Saxony; at Harzgerode, in the Harz; at Alston Moor, and in Cornwall, England; and along the Alps, in Styria and Carinthia. Cleavage masses are present in the cryolite from Greenland.

Workable beds of the ore are present in Columbia Co., and at Rossie, in St. Lawrence Co., N. Y.; in the coal regions of Pennsylvania and Ohio, and in clay beds along the Patapsco River, in Maryland. The massive or nodular ore from clay banks is known as *ironstone.* The impure bedded siderite interstratified with the coal shales is known as *black-band ore.*

Production.—Only 10,346 tons of siderite were produced in the United States during 1912, all of it coming from the bedded deposits in Ohio. This was valued at $20,000.

Rhodochrosite ($MnCO_3$)

This mineral sometimes occurs in distinct crystals of a rose-red color; but it is usually found in cleavable masses, in a compact form, or as a granular aggregate. Sometimes it is in incrustations. It is not of commercial importance in North America.

Pure manganese carbonate containing 61.7 per cent MnO and 38.3 per cent CO_2 is rare. The mineral is usually impure through the addition of the carbonates of iron, calcium, magnesium or zinc.

The most prominent forms on crystals of rhodochrosite are $R(10\bar{1}1)$, $-\frac{1}{2}R(01\bar{1}2)$, $\infty P2(11\bar{2}0)$, $oR(0001)$ and various scalenohedrons.

Its cleavage is perfect parallel to R. The mineral is brittle. Its hardness is about 4 and its density about 3.55. Its luster is vitreous, and its color red, brown, or yellowish gray. Its streak is white. When

heated it begins to lose CO_2 at about 320°; but its dissociation temperature is 632°.

The mineral is infusible, but when heated before the blowpipe it decrepitates and changes color. When treated in the borax bead it gives the violet color of manganese, and when fused with soda on charcoal it yields a bluish green manganate. It dissolves in hot hydrochloric acid.

There are but few minerals resembling pure rhodochrosite in appearance. From all of these, except the silicate, *rhodonite* (p. 380), it is distinguished by its reaction for manganese. It is distinguished from rhodonite by its hardness, its cleavage and its effervescence with acids. The impure varieties are very like some forms of *siderite*, from which, of course, the manganese test will distinguish it.

Synthesis.—Small rhombohedrons of rhodochrosite have been produced by heating a solution of $MnSO_4$ with an excess of $CaCO_3$ at 200° in a closed tube.

Occurrence and Origin.—Rhodochrosite occurs in veins associated with ores of silver, lead, copper and other manganese ores and in bedded deposits. It is the result of hydrothermal or contact metamorphism, and of weathering of other manganese-bearing minerals.

Localities.—The mineral is found at Schemnitz, in Hungary; at Nagyag, in Transylvania; at Glendree, County Clare, Ireland, where it forms a bed beneath a bog; at Washington, Conn., in a pulverulent form; at Franklin, N. J.; at the John Reed Mine, Aliconte, Lake Co., and at Rico, Colo.; at Butte City, Mont.; at Austin, Nev., and on Placentia Bay, Newfoundland. The Colorado and Montana specimens are well crystallized.

Uses.—The mineral is mined with other ores of manganese. Occasionally it is employed as a gem stone.

Smithsonite ($ZnCO_3$)

Smithsonite, or "dry-bone ore," is rarely well crystallized. It appears as druses, botryoidal and stalactitic masses, as granular aggregates and as a friable earth.

In $ZnCO_3$ there are 64.8 per cent ZnO and 35.2 per cent CO_2. Smithsonite usually contains iron and manganese carbonates, often small quantities of calcium and magnesium carbonates and sometimes traces of cadmium. A specimen from Marion, Arkansas, gave:

ZnO	CdO	FeO	CaO	CuO	CO_2	CdS	SiO_2	Total
64.12	.63	.14	.38	tr.	34.68	.25	.06	100.26

The mineral is closely isomorphous with calcite, $R(10\bar{1}1)$, $-\frac{1}{2}R(01\bar{1}2)$, $4R(40\bar{4}1)$, $\infty R2(11\bar{2}0)$, $oR(0001)$ and $R^3(21\bar{3}1)$ being present on many crystals. The R faces are rough or curved.

Its cleavage is parallel to $R(10\bar{1}1)$. Its hardness is 5 and its density about 4.4. The luster of the mineral is vitreous, its streak is white and its color white, gray, green or brown. It is usually translucent, occasionally transparent. When heated to 300° for one hour it loses all of its CO_2.

When heated in the closed tube CO_2 is driven off, leaving ZnO as a yellow residue while hot, changing to white on cooling. The mineral is infusible before the blowpipe. If a small fragment be moistened with cobalt nitrate solution and heated in the oxidizing flame it becomes green on cooling. When heated on charcoal a dense white vapor is produced. This forms a yellow coating on the coal, which, when it cools, turns white. If this be moistened with cobalt nitrate and reheated in the oxidizing flame it is colored green.

The above reactions for zinc, together with the effervescence of the mineral in hot hydrochloric acid distinguish smithsonite from all other compounds.

Smithsonite forms pseudomorphs after sphalerite and calcite and is pseudomorphed by quartz, limonite, calamine and goethite.

Synthesis.—Microscopic crystals of smithsonite may be produced by precipitating a zinc sulphate solution with potassium bicarbonate and allowing the mixture to stand for some time.

Occurrence.—Smithsonite occurs in beds and veins in limestones, where it is associated with galena and sphalerite and usually with calamine (p. 396). It is especially common in the upper, oxidized zone of veins of zinc ores and as a residual deposit covering the surface of weathered limestone containing zinc minerals.

Localities.—The mineral is found at Nerchinsk, Siberia; Bleiberg, in Carinthia; Altenberg, Aachen; Province of Santander, Spain; at Alston Moor and other places in England; at Donegal, in Ireland; at Lancaster, Penn.; at Dubuque, Iowa; in Lawrence and Marion Counties, Arkansas; and in the lead districts of Wisconsin and Missouri (see galena and sphalerite).

The Wisconsin and Missouri localities are the most important ones in North America. Here the ore occurs in botryoidal, in stalactitic and in earthy, compact, cavernous masses of a dull yellow color incrusted with druses of smithsonite crystals, of calamine and of other minerals, principally of lead. This is the variety known as "dry bone."

Uses.—The mineral was formerly an important ore of zinc, being

mined alone for smelting. It is now mined only in connection with calamine and other zinc ores, and all are worked up together. A translucent green or greenish blue variety occurring at Laurium, Greece, and at Kelly, New Mexico, is sometimes employed for ornamental purposes. About $650 worth of the material from New Mexico was utilized as gem material in 1912.

ARAGONITE DIVISION

This division of the carbonates includes the orthorhombic (rhombic bipyramidal) dimorphs of the members of the calcite group which, together, form a well characterized isodimorphous group. The carbonate of calcium is found well crystallized in both divisions, but the other carbonates are common to one only. They actually occur in both divisions, but they are found as common members of one and only as isomorphous mixtures with other more common forms in the other. Thus, barium carbonate is a common orthorhombic mineral under the name of *witherite*. It occurs also with $CaCO_3$ in mixed crystals under the name *baricalcite*, or *neotype*, which is hexagonal. (See also p. 212 and p. 213.)

The common members of the aragonite division are:

Aragonite	$CaCO_3$	Sp. Gr. = 2.936	$a : b : c$ = .6228 : 1 : .7204
Strontianite	$SrCO_3$	= 3.706	= .6090 : 1 : .7266
Witherite	$BaCO_3$	= 4.325	= .5949 : 1 : .7413
Cerussite	$PbCO_3$	= 6.574	= .6102 : 1 : .7232

Aragonite ($CaCO_3$)

Aragonite occurs in a great variety of forms. Sometimes it is in distinct crystals, but more frequently it is in oölitic globular and reniform masses, in divergent bundles of fibers or of needle-like forms, in stalactites and in crusts.

In composition aragonite is like calcite. It often contains small quantities of the carbonates of strontium, lead or zinc.

Crystals are often acicular with steep domes predominating. Some of the simplest crystals consist of $\infty P(110)$, $\infty P\breve{\infty}(010)$, $\frac{3}{2}P\breve{\infty}(032)$, $P\breve{\infty}(011)$, $4P(441)$, $9P(991)$ and $\infty P\breve{2}(120)$ (Fig. 116). Twinning is common. The twinning plane is often $\infty P(110)$. By repetition this gives rise to pseudohexagonal forms, resembling an hexagonal prism and the basal plane (see Figs. 117 and 118). The angle $110 \wedge 1\bar{1}0 = 63° 48'$.

The cleavage of aragonite is distinct parallel to $\infty P\breve{\infty}(010)$ and indistinct parallel to $\infty P(110)$. Its hardness is 3.5–4 and density about 2.93. Its luster is vitreous and its color white, often tinged with gray,

green or some other light shade. Its streak is white and the mineral is transparent or translucent. Its indices of refraction for yellow light are: $\alpha = 1.5300$, $\gamma = 1.6857$. At 400° it passes over into calcite.

Before the blowpipe aragonite whitens and falls to pieces. Otherwise its reactions are like those of *calcite*, from which it can be distin-

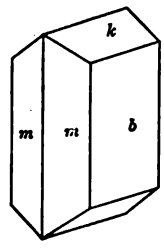


FIG. 116.

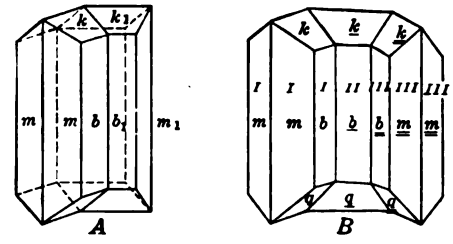


FIG. 117.

FIG. 116.—Aragonite Crystal with ∞P, 110 (*m*); ∞P$\breve{\infty}$, 010 (*b*) and P$\breve{\infty}$, 011 (*k*).
FIG. 117.—Aragonite Twin and Trilling Twinned about ∞P (110).

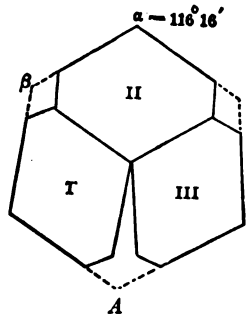


FIG. 118.—Trilling of Aragonite Twinned about ∞P (110). (*A*) Cross-section. (*B*) Resulting pseudohexagonal group, resembling an hexagonal prism and basal plane.

guished by its crystallization, its lack of rhombohedral cleavage and its density.

Synthesis.—Solutions of $CaCO_3$ in dilute H_2CO_3 form crystals of aragonite when evaporated at a temperature of about 90°. In general, hot solutions of the carbonate deposit aragonite, while cold solutions deposit calcite. If the solution contains some sulphate or traces of strontium or lead carbonates, mixed crystals consisting principally of the aragonite molecule are formed at ordinary temperature.

Occurrence and Origin.—Aragonite occurs in beds, usually with gypsum. It is also deposited from hot waters and from cold waters

containing a sulphate (as from sea water). The pearly layer of oyster shells and the body of the shells of some other mollusca are composed of calcium carbonate crystallizing like aragonite. Aragonite is often changed by paramorphism into calcite, pseudomorphs of which after the former mineral are quite common.

Localities.—The mineral is found at Aragon, Spain; at Bilin, in Bohemia; in Sicily; at Alston Moor, England; and at a number of other places in Europe. It occurs in groupings of interlacing slender columns (*flos ferri*), in the iron mines of Styria. Stalactites are abundant at Leadhills, Lanarkshire, Scotland, and a silky fibrous variety known as *satinspar*, at Dayton, England.

In the United States crystallized aragonite occurs at Mine-la-Motte, Mo., and in the lands of the Creek Nation, Oklahoma. Flos ferri has been reported from the Organ Mts., New Mexico, and fibrous masses from Hoboken, N. J., Lockport, Edenville and other towns in New York and from Warsaw, Ill.

Strontianite ($SrCO_3$)

In general appearance and in its manner of occurrence strontianite resembles aragonite. Its crystals are often acicular in habit though repeated twins are common. The angle $110 \wedge 1\bar{1}0 = 62° 41'$.

The composition of pure strontianite is $SrO = 70.1$, $CO_2 = 29.9$, but the mineral usually contains an admixture of the barium and calcium carbonates.

Strontianite is brittle, its hardness is 3.5–4 and its density 3.7.

Before the blowpipe strontianite swells and colors the flame with a crimson tinge. It dissolves in hydrochloric acid. The solution imparts a crimson color to the blowpipe flame. When treated with sulphuric acid it yields a precipitate of $SrSO_4$. Its refractive indices for yellow light are: $\alpha = 1.5199$, $\gamma = 1.668$. Its dissociation temperature is 1155°.

Aragonite, witherite ($BaCO_3$) and strontianite are so similar in appearance and in general properties that they can be distinguished from one another best by their chemical characteristics. They are all soluble in hydrochloric acid and these solutions impart distinctive colors to the blowpipe flame (see p. 477).

Syntheses.—Crystals of strontianite are obtained by precipitating a hot solution of a strontium salt by ammonium carbonate, and by cooling a solution of $SrCO_3$ in a molten mixture of NaCl and KCl.

Occurrence.—Strontianite occurs in veins in limestone and as an

alteration product of the sulphate (celestite) where this is exposed to the weather. It is probably in all cases a deposit from water.

Localities.—Strontianite is the most common of all strontian compounds. It frequently occurs as the filling of metallic veins. It forms finely developed crystals at the Wilhelmine Mine near Munster, Westphalia. At Schoharie, N. Y., it occurs as crystals and as granular masses in nests in limestone. It is found also at other places in New York, in Mifflin Co., Penn., and on Mt. Bannell near Austin, Texas.

Uses.—Strontium compounds are little used in the arts. The hydroxide is employed to some extent in refining beet sugar and the nitrate in the manufacture of "red fire." Other compounds are used in medicine. All the strontium salts used in the United States are imported.

Witherite ($BaCO_3$)

Witherite differs very little in appearance or in manner of occurrence from aragonite. Its crystals are nearly always in repeated twins that have the habit of hexagonal pyramids (Fig. 119). The angle $110 \wedge 1\bar{1}0 = 62° 46'$.

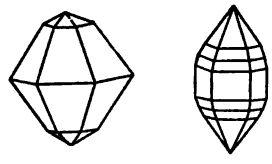


FIG. 119.—Witherite Twinned about ∞ P (110), thus Imitating Hexagonal Combinations.

When pure the mineral contains 77.7 per cent BaO and 22.3 per cent CO_2.

It is much heavier than the calcium carbonate, its density being 4.3. Its hardness is 3 to 4. Its refractive index for yellow light, $\beta = 1.740$. Its dissociation temperature is 1352°.

It dissolves readily in dilute hydrochloric acid with effervescence, and from this solution, even when dilute, sulphuric acid precipitates a heavy white precipitate of $BaSO_4$, which, when heated in the blowpipe flame, imparts to it a yellowish green color.

Witherite is distinguished from the other carbonates by its crystallization, and the color it imparts to the blowpipe flame.

Syntheses.—Crystals are produced by precipitating a hot solution of a barium salt with ammonium carbonate, and by cooling a molten magma composed of NaCl and $BaCO_3$.

Localities.—Witherite is not a very common mineral in the United States, but it occurs in large quantity associated with lead minerals in veins at Alston Moor, in Cumberland and near Hexham, in Northumberland, England. Some of the crystals found in these places measure as much as six inches in length.

Its best known locality in the United States is Lexington, Kentucky, where the mineral is associated with the sulphate, barite.

Uses.—It is used to some extent as a source of barium compounds. The importations of the mineral during 1912 aggregate $25,715.

Cerussite ($PbCO_3$)

Cerussite generally occurs in crystals and in granular, earthy and fibrous masses of a white color.

The pure lead carbonate contains $CO_2 = 16.5$ and $PbO = 83.5$, but the mineral usually contains in addition some $ZnCO_3$.

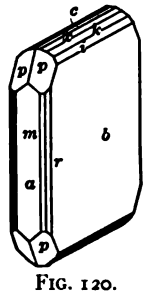


FIG. 120.

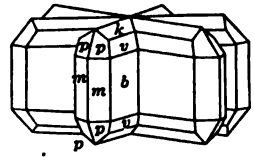


FIG. 121.

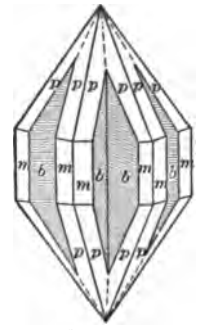


FIG. 122.

FIG. 120.—Cerussite Crystal with ∞P, 110 (*m*); ∞P$\bar{\infty}$, 100 (*a*); ∞P$\breve{\infty}$, 010 (*b*); P, 111 (*p*); ∞P$\breve{3}$, 130 (*r*); 2P$\breve{\infty}$, 021 (*i*); P$\breve{\infty}$, 011 (*k*); ½P$\breve{\infty}$, 012 (*x*) and oP, 001 (*c*).

FIG. 121.—Cerussite Trilling Twinned about ∞P(110).

FIG. 122.—Cerussite Trilling Twinned about ∞P$\breve{3}$(130).

Its simple crystals are tabular combinations of ∞P(110), ∞P$\breve{\infty}$ (010) ∞P$\bar{\infty}$ (100) and various brachydomes (Fig. 120), and these are often twinned in such a way as to produce six rayed stars (Fig. 121), or other symmetrical forms (Fig. 122). Groups of interpenetrating crystals are also common. The angle $110 \wedge 1\bar{1}0 = 62° 46'$.

The color of the mineral is usually white, but its surface is frequently discolored by dark decomposition products. Its luster is adamantine or vitreous and its hardness is 3–3.5. Its density = 6.5. Its refractive indices for yellow light are: $\alpha = 1.8037$, $\beta = 2.0763$, $\gamma = 2.0780$.

The mineral is dissolved by nitric acid with effervescence and by potassium hydroxide. Before the blowpipe it decrepitates, turns yellow and changes to lead oxide. On charcoal it is reduced to a metallic globule, and yields a white and yellow coating.

Cerussite is not easily confused with other minerals. It is well characterized by its high specific gravity, its reaction for lead, and is distinguished from the sulphate (*anglesite*) by effervescence with hot acids.

Syntheses.—Crystals have been obtained by heating lead formate with water in a closed tube, and by treatment of a lead salt by a solution of ammonium carbonate at a temperature of 150°–180°.

Occurrence and Origin.—The mineral occurs at all localities at which other lead compounds are found, since it is often produced from these

FIG. 123.—Radiate Groups of Cerussite on Galena from Park City District, Utah. (*After J. M. Boutwell.*)

latter by the action of the atmosphere and atmospheric water. It is, therefore, usually found in the upper portions of veins.

Localities.—Cerussite crystals of great beauty are found in many of the lead-producing districts of Europe and also at Phoenixville, Penn.; near Union Bridge, in Maryland; at Austin's Mines, Wythe Co., Virginia, and occasionally in the lead mines of Wisconsin and Missouri. In the West it occurs at Leadville, Colo.; at the Flagstaff and other mines in Utah (Fig. 123), and at several different mines in Arizona.

Uses.—It is mined with other lead compounds as an ore of the metal.

Dolomite ($MgCa(CO_3)_2$)

Dolomite is apparently isomorphous with calcite but the etch figures on rhombohedral faces prove it to belong in the trigonal rhombohedral class. It occurs as crystals and in all the forms characteristic of calcite except the fibrous.

Nearly all calcite contains more or less magnesium carbonate, but most of the mixtures are isomorphous with calcite and magnesite. When the ratio between the two carbonates reaches 54.35 per cent $CaCO_3$: 45.65 per cent $MgCO_3$, which is equal to the ratio between the molecular weights of the two substances, or in other words when the two carbonates are present in the compound in the ratio of one molecule to one molecule, the mineral is called dolomite. The calculated composition of dolomite ($MgCa(CO_3)_2$) is 30.4 per cent CaO; 21.7 per cent MgO and 47.8 per cent CO_2.

The crystals of dolomite are usually rhombohedral combinations of the rhombohedron $R(10\bar{1}1)$ with the scalenohedron $R^3(21\bar{3}1)$ (Fig. 124), and its tetartohedral forms, and often the prism $\infty P2(11\bar{2}0)$ and the basal plane. Its axial ratio is $a : c = 1 : .8322$. Twins are not rare, with $oR(0001)$ and $R(10\bar{1}1)$ the twinning planes. The R planes are often curved, frequently with concave surfaces (Fig. 125). The angle $10\bar{1}1 \wedge \bar{1}101 = 73°$.

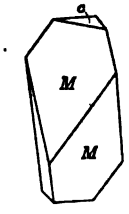


FIG. 124.—Dolomite Crystal with 4R, $40\bar{4}1$ (*M*) and oP, 0001 (*c*).

The cleavage of dolomite is perfect parallel to R. The mineral is brittle. Its hardness is 3.5–4 and density 2.915. Its luster is vitreous or pearly and its color white, red, green, gray or brown. Its streak is always white and the mineral is translucent or transparent. Its refractive indices for yellow light are: $\omega = 1.6817$, $\epsilon = 1.5026$. The important varieties recognized are:

Pearlspar, with curved faces having a pearly luster.

Granular or saccharoidal, including many marbles and magnesian limestones.

Dolomitic limestone, including much hydraulic limestone.

Many dolomites are intermixed with the carbonates of iron, manganese, cobalt or zinc and these are known as ferriferous dolomite, etc.

Dolomite behaves like calcite before the blowpipe and in the closed tube. It, however, dissolves only slowly, if at all, in cold hydrochloric acid, except when very finely powdered, though dissolving readily with effervescence in hot acid.

The reaction toward cold acid and its greater hardness easily distinguish dolomite from *calcite*. It is distinguished from *magnesite* by the flame reaction.

Occurrence and Origin.—Dolomite, like the calcium carbonate, occurs crystallized in veins, and as granular masses forming great beds of rock. It is a precipitate from solutions and a metasomatic alteration product of calcite.

Localities.—Its crystals are present at many places, among them Bex, in Switzerland; Traversella, in Piedmont; Guanajuato, in Mexico; Roxbury, in Vermont; Hoboken, N. J.; Niagara Falls, the Quarantine

FIG. 125.—Group of Dolomite Crystals from Joplin, Mo. Flat Rhombohedrons with Curved Faces.

Station, and Putnam, N. Y.; Joplin, Mo.; and Stony Point, N. C. It is also very widely spread as beds of dolomitic limestone.

Uses.—Dolomite is used for many of the purposes served by calcite; indeed, much of the material used as marble, limestone, etc., contains a large percentage of magnesium carbonate. It is not, however, used as a flux or in the manufacture of Portland cement, nor as a source of lime.

Ankerite ($Ca(Mg \cdot Fe)(CO_3)_2$) is a ferruginous dolomite. It is an isomorphous mixture of the carbonates of calcium, magnesium and iron, in which the $FeCO_3$ replaces a part of the $MgCO_3$ in dolomite. It is usually in rhombohedral crystals, with the angle $10\bar{1}1 \wedge \bar{1}101 = 73° 48'$. Its color is white, gray or red and its streak is white. Its hardness $= 3.5–4$, and its density $= 2.98$. It also occurs in coarse and fine-grained granular masses. Ankerite is infusible before the blowpipe. In the

closed tube it darkens and when heated on charcoal it becomes magnetic. It occurs in veins, especially those containing iron minerals. It has been found at Antwerp and other places in northern New York.

CALCIUM-BARIUM CARBONATES

Carbonates of the general composition $CaBa(CO_3)_2$ occur (1) as a series of mixed crystals isomorphous with calcite under the name *baricalcite*; (2) as a series of mixed crystals isomorphous with aragonite known as *alstonite* or *bromlite*, and (3) a typical double salt, *barytocalcite*, which is monoclinic. Both alstonite and barytocalcite occur in veins of lead ores and of barite ($BaSO_4$).

Barytocalcite, $CaBa(CO_3)_2$ is monoclinic (prismatic class), with $a : b : c = .7717 : 1 : .6255$ and $\beta = 73° 52'$. It forms crystals bounded by $\infty P\bar{\infty}$ (100), ∞P(110), oP(001), and a series of clinopyramids, of which $2P\bar{2}(12\bar{1})$ and $5P\bar{5}(15\bar{1})$ are common. It also occurs massive. Its perfect cleavage is parallel to ∞P(110). The mineral is white, gray, greenish or yellowish. Its streak is white, hardness = 4 and sp. gr. = 3.665. It is transparent or translucent. Before the blowpipe fragments fuse on thin edges, and assume a pale green color, due to the presence of a little manganese. The mineral is soluble in HCl. Its principal occurrence is Alston Moor, Cumberland, England.

BASIC CARBONATES

The basic carbonates are salts in which all or a portion of the hydrogen of carbonic acid is replaced by the hydroxides of metals. There are only three minerals belonging to the group that need be referred to here. Two are copper compounds. One is the bright green *malachite* and the other the blue *azurite*. The composition of the former may be represented by the formula $\begin{matrix} CuOH \\ CuOH \end{matrix}\!\!>\!CO_3$, and that of the latter by $\begin{matrix} CuOH \\ Cu \\ CuOH \end{matrix}\!\!>\!(CO_3)_2$. Both are used to some extent as ores of the metal, though their value for this purpose is not great at the present time. They may easily be distinguished from all other minerals by their distinctive colors, by the fact that they yield water in the closed tube and by their effervescence with acids. The third mineral (*hydrozincite*) is a white substance that occurs as earthy or fibrous incrustations on other zinc compounds. Its composition corresponds to $2ZnCO_3 \cdot 3Zn(OH)_2$.

Its hardness = 2–2.5 and its specific gravity is about 3.7. Only the two copper compounds are described in detail.

Malachite ($(CuOH)_2CO_3$)

Malachite usually occurs in fibrous, radiate, stalactitic, granular or earthy, green masses, or as small drusy crystals covering other copper compounds. The mineral contains, when pure, 19.9 per cent CO_2, 71.9 per cent CuO and 8.2 per cent H_2O.

Well defined crystals are usually very small monoclinic prisms (monoclinic prismatic class), with an axial ratio .8809 : 1 : .4012 and $\beta = 61° 50'$. Their predominant forms are $\infty P \bar{\infty}$ (100), $\infty P \breve{\infty}$ (010), ∞P(110), and oP(001). Contact twins are common, with $\infty P \bar{\infty}$ (100) the twinning plane (Fig. 126). The angle $110 \wedge 1\bar{1}0 = 75° 40'$.

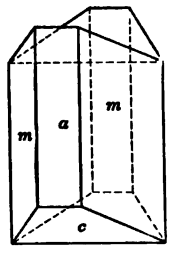


FIG. 126.—Malachite Crystal with ∞P, 110 (*m*); $\infty P \bar{\infty}$, 100 (*a*), and oP, 001 (*c*) Twinned about *a*.

The pure mineral is bright green in color and has a light green streak. It possesses a vitreous luster, but this becomes silky in fibrous masses and dull in massive specimens. Crystals are translucent and massive pieces are opaque. Translucent pieces are pleochroic in yellowish green and dark green tints. The cleavage is perfect parallel to oP(001). The hardness of malachite is 3.5–4, and its density about 3.9. Its refractive index, β, for yellow light = 1.88.

Malachite turns black and fuses before the blowpipe and tinges the flame green. With Na_2CO_3 on charcoal it yields a copper globule. It is difficultly soluble in pure water, but is easily dissolved in water containing CO_2. It is soluble with effervescence in HCl and its solution becomes deep blue on the addition of an excess of ammonia. When heated in a closed glass tube, it gives an abundance of water. Boiled with water it turns black and loses its CO_2.

Malachite, on account of its characteristic color, may be easily distinguished from all other minerals but some varieties of *turquoise* and a few copper compounds, such as *atacamite* (p. 144). It may be distinguished from all of these by its effervescence with acids.

Synthesis.—Malachite crystals have been obtained with the form of natural crystals by heating a solution of copper carbonate in ammonium carbonate.

Occurrence and Origin.—Malachite is a frequent decomposition product of other copper minerals, being formed rapidly in moist places.

It occurs abundantly in the upper oxidized portions of veins of copper ore, where it is associated with azurite, cuprite, copper, limonite and the sulphides of iron and copper, often pseudomorphing the copper minerals. The green stain noticed on exposed copper trimmings of buildings is composed in part of this substance.

Localities.—The mineral occurs in all copper mines. At Chessy, France, it forms handsome pseudomorphs after cuprite. In the United States it has been found in good specimens at Cornwall, Lebanon Co., Penn.; at Mineral Point, Wisconsin; at the Copper Queen Mine, Bisbee, and at the Humming Bird Mine, Morenci, Arizona, and in the Tintic district, Utah.

Uses.—In addition to its use as an ore of copper the radial and massive forms of malachite are employed as ornamental stones for inside decoration. The massive forms are also sawn into slabs and polished for use as table tops and are turned into vases, etc.

Production.—As malachite is mined with other copper compounds, the quantity utilized as an ore of the metal is not known. The amount produced in the United States during 1912 for ornamental purposes was valued at $1,085. This, however, included also a mixture of malachite and azurite.

Azurite ($Cu(CuOH)_2(CO_3)_2$)

Azurite is more often found in crystals than is malachite. It occurs also as veins and incrustations and in massive, radiated, and earthy

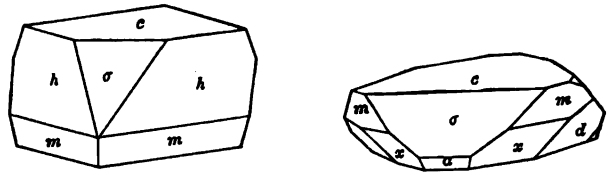


FIG. 127.—Azurite Crystals with oP, 001 (*c*); $-P\bar{\infty}$, 101 (*σ*); $\infty P\bar{\infty}$, 100 (*a*); P, $\bar{1}11$ (*x*), ∞P, 110 (*m*); $-2P$, 221 (*h*); $\frac{4}{3}P\breve{2}$, $2\bar{4}3$ (*d*) and $P\breve{\infty}$, 011 (*f*).

forms associated with malachite and other copper compounds. Its most frequent associate is malachite, into which it readily alters.

In composition azurite is 25.6 per cent CO_2, 69.2 per cent CuO, and 5.2 per cent H_2O. It changes rapidly to malachite, and sometimes is reduced to copper.

The crystals are tabular, prismatic, or wedge-shaped monoclinic forms (monoclinic prismatic class), with an axial ratio $a : b : c = .8501 : 1 : 1.7611$, and $\beta = 87° 36'$. They are usually highly modified, 58 or

more different planes having been identified on them. The predominant ones are oP(001), $-P\bar{\infty}$ (101), ∞P(110), $-2P$(221) and $\infty P\bar{\infty}$ (100). (Fig. 127.) The angle $110 \wedge 1\bar{1}0 = 80° 40'$.

The mineral is dark blue, vitreous, and translucent or transparent, and is pleochroic in shades of blue. It is brittle. Its streak is light blue, its hardness 3.5–4 and density 3.8. Its cleavage is distinct parallel to $P\bar{\infty}$ (011).

The blowpipe and chemical reactions for azurite are the same as those for malachite. By them the mineral is easily distinguished from the few other blue minerals known.

Synthesis.—Crystals have been formed on calcite by allowing fragments of this mineral to lie in a solution of $CuNO_3$ for a year or more.

Occurrence.—The mineral occurs in the oxidized zone of copper veins. It is an intermediate product in the change of other copper compounds to malachite.

Localities.—Azurite occurs in beautiful crystals at Cressy, France; near Redruth, in Cornwall; at Phoenixville, Penn.; at Mineral Point, Wis.; at the Copper Queen Mine, Bisbee, Ariz.; at the Mammoth Mine, Tintic district, Utah; at Hughes's Mine, California, and at many other copper mines in this country and abroad.

From Morenci, Ariz., Mr. Kunz describes specimens consisting of spherical masses composed of alternating layers of malachite and azurite, which, when cut across, yield surfaces banded by alternations of bright and dark blue colors.

Uses.—Azurite is mined with other copper minerals as an ore of copper. It is also used to a slight extent as an ornamental stone (see malachite).

HYDROUS CARBONATES

The hydrous carbonates are salts containing water of crystallization. They are carbonates of sodium or of this metal with calcium or magnesium. Some of them occur in abundance in the waters of salt or bitter lakes, but very few are known to occur in any large quantity in solid form. Among the commonest are:

Soda or natron	$Na_2CO_3 \cdot 10H_2O$	monoclinic
Trona	$HNa_3(CO_3)_2 \cdot 2H_2O$	monoclinic
Gaylussite	$Na_2Ca(CO_3)_2 \cdot 5H_2O$	monoclinic
Hydromagnesite	$Mg_4(OH)_2(CO_3)_3 \cdot 3H_2O$	orthorhombic

These minerals occur either in the muds of lakes or as crusts upon the mud or upon other minerals.

Natron occurs only in solution and in the dry mud on the borders of lakes.

Trona, or urao, ($HNa_3(CO_3)_2 \cdot 2H_2O$) is found as crystals in the mud of Borax Lake, California, as a massive bed in Churchill Co., Nevada, and as thin coatings on rocks in other places. Its crystallization is monoclinic (prismatic class), with the axial ratio, 2.8426 : 1 : 2.9494 and $\beta = 76° 31'$. Its crystals are usually bounded by oP(001), $\infty P \bar{\infty}$ (100), $-P(111)$ and $+P(\bar{1}11)$ (Fig. 128). Fibrous and massive forms are common. The mineral has a perfect cleavage parallel to $\infty P \bar{\infty}$ (100). It is gray or yellowish and has a colorless streak. It has a vitreous luster, a hardness of 2.5–3, and a density of 2.14. It is soluble in water and has an alkaline taste. It exhibits the usual reactions for Na and for carbonates.

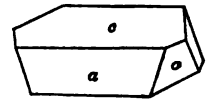


FIG. 128.—Trona Crystal with oP, 001 (*c*); $\infty P \bar{\infty}$, 100 (*a*) and +P, $\bar{1}11$ (*o*).

Gaylussite ($Na_2Ca(CO_3)_2 \cdot 5H_2O$) also occurs as crystals in the muds of certain lakes, especially Soda Lake, near Ragtown, Nevada, and Merida Lake, Venezuela, and in clays under swamps in Railroad Valley, in Nevada. Its crystals are monoclinic (prismatic class) with $a : b : c = 1.4897 : 1 : 1.4442$ and $\beta = 78° 27'$. They are usually bounded by $\infty P(110)$, $P \breve{\infty}$ (011), and $\frac{1}{2}P(\bar{1}12)$ (Fig. 129), or by these planes and oP(001) and $\infty P \bar{\infty}$ (100). They are either prismatic because of the predominance of $P \breve{\infty}$ (011) and oP(001), or are octahedral in habit because of the nearly equal development of $P \breve{\infty}$ (011) and $\infty P(110)$. Their cleavage is perfect parallel to $\infty P(110)$.

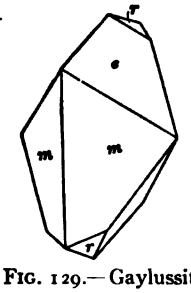


FIG. 129.—Gaylussite Crystal with ∞P, 110 (*m*); $P \breve{\infty}$, 011 (*e*) and $\frac{1}{2}P$, $\bar{1}12$ (*r*).

The mineral is white or yellowish and translucent. Its hardness is 2–3 and density 1.99. It is very brittle. When heated in the closed tube it decrepitates and becomes opaque. It loses its water at 100°. In the flame it melts easily to a white enamel and colors the flame yellow. It is partially soluble in water, leaving a white powdery residue of $CaCO_3$ and is entirely soluble in acids with effervescence. The mineral occurs in such large quantity in the clays underlying swamps in Railroad Valley, Nevada, that its use has been suggested as a source of Na_2CO_3.

CHAPTER XII

THE SULPHATES

THE sulphates are salts of sulphuric acid. A large number are known to occur in nature but many of them are dissolved in the waters of salt lakes. Of the remaining ones only a few are very common. These may be divided into an anhydrous normal group, a basic group and a hydrated group. In addition, there are several minerals that are sulphates mixed with chlorides or carbonates.

All the sulphates that are soluble in water give the test for sulphuric acid. When heated with soda on charcoal they are reduced to sulphides. The mass when placed on a silver coin and moistened with a drop of water or of hydrochloric acid partly dissolves and stains the silver dark brown or black.

The sulphates when pure are all white and transparent, and are all nonconductors of electricity.

ANHYDROUS SULPHATES

NORMAL SULPHATES

The anhydrous normal sulphates have the general formula R'_2SO_4 or $R''SO_4$. The most common ones are sulphates of the alkaline earths and lead. They belong in a single group which is orthorhombic. The few less common ones are sulphates of the alkalies or of the alkalies and alkaline earths. Only two of the latter are described.

Glauberite ($Na_2Ca(SO_4)_2$)

Glauberite may be regarded as a double salt of the composition $Na_2SO_4 \cdot CaSO_4$, which requires 51.1 per cent Na_2SO_4 and 48.9 per cent $CaSO_4$. The mineral contains 22.3 per cent Na_2O, 20.1 per cent CaO and 57.6 per cent SO_3.

It nearly always occurs in monoclinic crystals (prismatic class), with an axial ratio 1.2209 : 1 : 1.0270 and $\beta = 67° 49'$. The most frequent combination is oP(001), $-P(111)$, $\infty P(110)$, $\infty P\bar{\infty}(100)$, $3P\bar{3}(31\bar{1})$ and $+P(11\bar{1})$, with oP(001) prominent (Fig. 130). The cleavage is perfect parallel to oP(001). The angle $110 \wedge 1\bar{1}0 = 96° 58'$.

Glauberite is yellow, gray or brick-red in color, is transparent or translucent and has a white streak, a vitreous luster and a conchoidal fracture. Its hardness is 2.5–3 and its specific gravity about 2.8. It is brittle. It is partly soluble in water, imparting to the solution a slight saltiness. The red color of many specimens is due to the presence of inclusions.

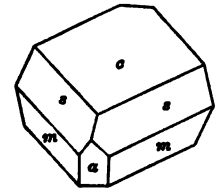


FIG. 130.—Glauberite Crystal with oP, 001 (*c*); ∞P, 110 (*m*); ∞P$\bar{\infty}$, 100 (*a*) and −P, 111 (*s*).

Before the blowpipe the mineral decrepitates, whitens and fuses easily to a white enamel, at the same time coloring the flame yellow. It is soluble in HCl and in a large quantity of water. In a small quantity of water it is partially dissolved with loss of transparency and the production of a deposit of $CaSO_4$.

It sometimes alters to calcite.

Occurrence.—Glauberite is associated with rock salt and other deposits from bodies of salt water. It is found at Villa Rubia, in Spain, and elsewhere in Europe, and in the Rio Verde Valley, Arizona and at Borax Lake, California.

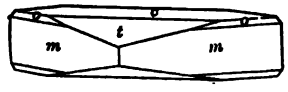


FIG. 131.—Thenardite Crystal with ∞P, 110 (*m*); P, 11$\bar{1}$ (*o*); $\frac{1}{6}$P$\bar{\infty}$, 106 (*t*) and oP, 001 (*c*).

Thenardite (Na_2SO_4) occurs as orthorhombic crystals in the vicinity of salt lakes, and in beds associated with other lake deposits. Its crystals have an axial ratio .5976 : 1 : 1.2524. They are commonly prismatic but those from California are tabular and are bounded by ∞P(110), oP(001), P(11$\bar{1}$), $\frac{1}{6}$P$\bar{\infty}$ (106), and ∞P$\bar{\infty}$ (100) (Fig. 131). Twins are common (Fig. 132).

The mineral is colorless, white or reddish and has a salty taste. Its hardness is 2–3 and its specific gravity 2.68. Its intermediate refractive index is 1.470. It is readily soluble in water. It occurs in extensive deposits in the Rio Verde Valley, Arizona, and as crystals at Borax Lake, California and on the shores of salt lakes in Central Asia and South America.

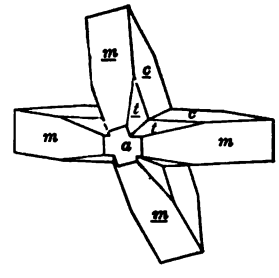


FIG. 132.—Thenardite Twinned about P$\bar{\infty}$ (011). Forms same as in Fig. 131 and ∞P$\bar{\infty}$, 100 (*a*).

BARITE GROUP

The barite group includes the sulphates of the alkaline earths and lead. They are all light colored minerals with a nonmetallic luster. They all crystallize in the orthorhombic system (bipyramidal class), and all have a hardness of about 4. The minerals comprising this group, with their axial ratios, are:

Anhydrite	$CaSO_4$	$a : b : c = .8932 : 1 : 1.0008$
Barite	$BaSO_4$	$= .8152 : 1 : 1.3136$
Celestite	$SrSO_4$	$= .7790 : 1 : 1.2800$
Anglesite	$PbSO_4$	$= .7852 : 1 : 1.2894$

Anhydrite ($CaSO_4$)

Calcium sulphate is dimorphous. The natural compound, anhydrite, is orthorhombic bipyramidal. In addition to this, there is another which passes over into anhydrite when shaken for a long time with boiling water. It is produced by dehydrating gypsum at about 100°. When moistened it combines with water and passes back to gypsum. It is probably triclinic. It is unstable under the conditions prevailing at the earth's surface and is, therefore, not found as a mineral.

Anhydrite occurs usually in fibrous, granular or massive forms, not often in crystals. When crystals occur they are commonly prismatic or tabular in habit.

In composition the mineral is 58.8 per cent SO_3 and 41.2 per cent CaO.

Its crystals are usually bounded by the three pinacoids oP(001), $\infty P\bar{\infty}$ (100), $\infty P\breve{\infty}$ (010) and P(111), $2P\breve{2}$(121), $3P\breve{3}$(131), $P\bar{\infty}$ (101) and $P\breve{\infty}$ (011). The prismatic types are usually elongated parallel to the macroaxis. The angle $110 \wedge 1\bar{1}0 = 83° 41'$.

Anhydrite fuses quite easily before the blowpipe and colors the flame reddish yellow. It is very slightly soluble in water but is completely dissolved in strong sulphuric acid. It cleaves parallel to the three pinacoids yielding rectangular fragments. Its hardness is 3–3.5 and density about 2.95. Its luster is vitreous in massive pieces and its color white, often with a distinct tinge of blue, gray or red. In small fragments it is translucent, but in large masses it is opaque. Its refractive indices for yellow light are: $\alpha = 1.5693$, $\gamma = 1.6130$.

It is distinguished from the other sulphates by its specific gravity and the color it imparts to the blowpipe flame.

Synthesis.—Its crystals have been produced by slowly evaporating a solution of gypsum in H_2SO_4.

Occurrence.—Anhydrite occurs as crystals implanted on the minerals of ore veins, as beds of granular masses associated with gypsum, and as crystalline masses in layers associated with rock salt—the two having been deposited by the evaporation of salt waters.

Localities.—The mineral is found at the salt mines of Stassfurt, in Germany; Hall, in Tyrol; Bex, in Switzerland; in the ore veins of Andreasberg, in Harz; Bleiberg, in Carinthia, and at many other places in Europe. At Lockport, N. Y., and at Nashville, Tenn., it occurs as crystals lining geodes in limestone, and at the mouths of the Avon and St. Croix Rivers in Nova Scotia it forms large beds associated with gypsum.

Uses.—Finely granular forms of the mineral are used for ornamental purposes, and as a medium for the use of sculptors. The massive variety is occasionally employed as a land plaster to enrich cultivated soils.

Barite ($BaSO_4$)

Barite, or heavy spar, usually occurs crystallized, though it is also often found massive and in granular, fibrous and lamellar forms. It is a common mineral associated with sulphide ores as a gangue.

The mineral is sometimes pure but it is usually intermixed with the isomorphous calcium and strontium sulphates. The pure mineral contains 34.3 per cent SO_3 and 65.7 per cent BaO. As usually mined it contains SiO_2, CaO, MgO, Al_2O_3, Fe_2O_3 and in some instances PbS_2 (galena).

The simple crystals are usually tabular or prismatic in habit. The tabular forms are commonly bounded by oP(001), ∞P(110) and the domes, P$\bar{\infty}$ (101), ½P$\bar{\infty}$ (102), 2P$\breve{\infty}$ (021), and P$\breve{\infty}$ (011), and sometimes P(111) and ∞P$\bar{\infty}$ (100) (Fig. 133). The prismatic forms are usually elongated in the direction of the *a* axis, and are bounded by the same planes as the tabular crystals (Fig. 134). Complex crystals are also abundant. They are often beautifully supplied with planes, the total number known on the species being about 100. The angle $110 \wedge 1\bar{1}0 = 78° 22\frac{1}{2}'$.

FIG. 133.—Barite Crystals with ∞P, 110 (*m*); ½P$\bar{\infty}$, 102 (*d*); P$\breve{\infty}$, 011 (*o*) and oP, 001 (*c*).

The cleavage of barite is perfect parallel to oP(001) and ∞P(110). It is brittle. Its hardness is about 3 and its density about 4.5. The

mineral is white, often with a tinge of yellow, brown, blue, or red. It is transparent or opaque and its streak is white. Its refractive indices for yellow light are: $\alpha = 1.6369$, $\gamma = 1.6491$.

Before the blowpipe barite decrepitates and fuses, at the same time coloring the flame yellowish green. The fused mass reacts alkaline to litmus paper. It is insoluble in acids.

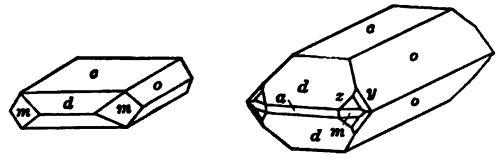


FIG. 134.—Barite Crystals with *m*, *d*, *o* and *c* as in Fig. 133. Also $\infty P \bar{\infty}$, 100 (*a*); P, 111 (*z*) and $P\breve{2}$, 122 (*y*).

The mineral barite is distinguished from the other sulphates by its high specific gravity and the color it imparts to the blowpipe flame.

Syntheses.—Crystals have been made by heating precipitated barium sulphate with dilute HCl in a closed tube at 150°, and by cooling a fusion of the sulphate in the chlorides of the alkalies or alkaline earths.

Occurrence and Origin.—Barite is a common vein-stone. It constitutes the gangue of many ore veins, particularly those of copper, lead and silver. It is found also as a replacement of limestone, which, when it weathers, leaves the barite in the form of fragments and nodules in a residual clay, and as a deposit in hot springs. In all cases it is believed to be a deposit from solutions.

Localities.—Barite occurs abundantly in England, Scotland, and on the continent of Europe. Crystals are found at Cheshire, Conn.; at DeKalb, St. Lawrence Co., N. Y.; at the Phoenix Mine in Cabarrus Co., N. C., and near Fort Wallace, New Mexico. Massive barite in pieces large enough to warrant polishing is found on the bank of Lake Ontario, at Sacketts Harbor, N. Y. It constitutes the filling of veins at many different places, more particularly in the southern Appalachians and in the Lake Superior region.

Preparation.—Much of the mineral that enters the trade in the United States is obtained from the deposits in residual clay. The rough material is washed, hand picked, crushed, ground and treated with sulphuric acid. The acid dissolves most of the impurities and leaves the powdered mineral white.

Uses.—The white varieties of the mineral are ground and the powder is used in making paints. The mineral is also employed in the manufacture of paper, oilcloth, enameled ware, and in the manufacture of barium salts, the most important of which is the hydroxide, which is employed in refining sugar.

The colored massive varieties, more especially stalactitic and fibrous forms, are sawn into slabs, polished and used as ornamental stones.

Production.—The quantity of barite mined in the United States during 1912 was over 37,000 tons, valued at $153,000. The principal producing states are Missouri, Tennessee and Virginia. The imports in the same year were about 26,000 tons of crude material, valued at $52,467 and 3,679 tons of manufactured material, valued at $26,848. Besides, there were imported $70,300 worth of artificial barium sulphate and about $280,000 worth of other barium salts, exclusive of witherite.

Celestite ($SrSO_4$)

Celestite occurs in tabular prismatic crystals, in fibrous and sometimes in globular masses. Though usually white, it often possesses a bluish tinge, to which it owes its name.

The theoretical composition of the mineral is 43.6 per cent SO_3 and 56.4 per cent SrO, but it often contains small quantities of the isomorphous Ca and Ba compounds.

Many celestite crystals are very similar in habit to those of barite.

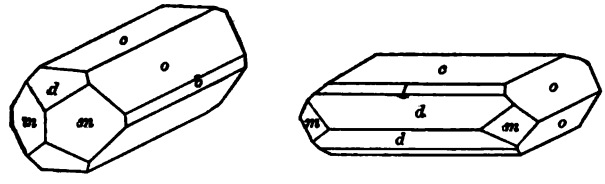


FIG. 135.—Celestite Crystals with ∞P, 110 (*m*); $\frac{1}{2}P\bar{\infty}$, 102 (*d*); $\frac{1}{4}P\bar{\infty}$, 104 (*r*); $\infty P\breve{\infty}$, 010 (*b*); $P\breve{\infty}$, 011 (*o*) and oP, 001 (*c*).

Tabular forms are perhaps more common (Figs. 135). Occasionally, pyramidal crystals are bounded by $P\breve{4}$(144), $\infty P\bar{\infty}$ (100), $P\breve{\infty}$ (011) and oP(001). These often have rounded edges and curved faces and thus come to have a lenticular shape. The angle $110 \wedge 1\bar{1}0 = 75° 50'$.

The cleavage of the mineral is perfect parallel to oP(001) and almost perfect parallel to ∞P(110). Its hardness is about 3 and its specific gravity 3.95. Its luster and streak are like those of barite. Its color is often pale blue and sometimes light red, but pure specimens are white or colorless. Its refractive indices for yellow light are: $\alpha = 1.6220$, $\gamma = 1.6237$.

Before the blowpipe celestite reacts like barite except that it tinges the flame crimson. This crimson color may be obtained more distinctly by fusing a little powder of the mineral on charcoal in the reduc-

ing flame and dissolving the resulting mass in a small quantity of hydrochloric acid, then adding some alcohol and igniting the mixture.

Syntheses.—Crystals of celestite are produced in ways analogous to those in which barite crystals are formed.

Occurrence and Origin.—Celestite occurs in beds with rock salt and gypsum, as at Bex, Switzerland; associated with sulphur, as at Girgenti, Italy; and in crystals and grains scattered through limestone, as at Strontian Island, Lake Erie, and in Mineral Co., W. Va., or as crystals lining geodes in the same rock. It is also sometimes found as a gangue in mineral veins. In some instances it was deposited by hot waters, in others by cold waters, and in others it was concentrated by the leaching of strontium-bearing limestones by atmospheric water.

Production and Uses.—Although the mineral occurs in large quantity at a number of places in the United States and Canada it is not mined. A small quantity of the strontium oxide is annually imported. Strontium salts, prepared from celestite in part, are used in the manufacture of fireworks and medicines and in refining sugar.

Anglesite ($PbSO_4$)

Anglesite occurs principally as crystals associated with galena and other ores of lead, but is found also massive, and in granular, stalactitic and nodular forms.

The theoretical composition of the mineral demands 73.6 per cent PbO and 26.4 SO_3.

Its orthorhombic crystals are usually prismatic or isometric in habit. Tabular habits are less common than in barite and celestite. The principal forms occurring are $\infty P\bar{\infty}$ (100), ∞P(110), $\frac{1}{2}P\bar{\infty}$ (102), and other macrodomes, $P\breve{\infty}$ (011) and various small pyramids, with oP(001), in addition, on the tabular crystals (Figs. 136, 137, 138). The angle $110 \wedge 1\bar{1}0 = 76^\circ\ 16\frac{1}{2}'$.

The cleavage of anglesite is distinct parallel to oP(001) and ∞ P(110). Its fracture is conchoidal. The mineral is white, gray or colorless and transparent, and is often tarnished with a gray coating. It has an adamantine or residuous luster, is brittle and has a colorless streak. Its hardness is 2.5–3 and sp. gr. 6.3–6.4. Impure varieties may be tinged with yellow, green or blue shades and in some cases may be opaque. Its refractive indices for yellow light are: $\alpha = 1.8771$, $\gamma = 1.8937$.

Before the blowpipe anglesite decrepitates. It fuses in the flame of a candle. On charcoal it effervesces when heated with the reducing flame and yields a button of metallic lead. In the oxidizing flame it

gives the lead sublimate. The mineral dissolves in HNO_3 with difficulty.

The mineral is characterized by its high specific gravity and the

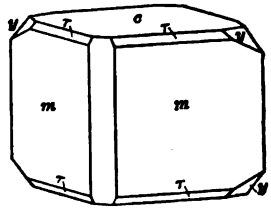


FIG. 136.

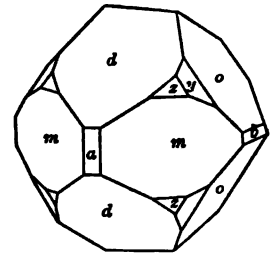


FIG. 137.

FIG. 136.—Anglesite Crystal with ∞P, 110 (*m*); $\infty P\bar{\infty}$, 100 (*a*); oP, 001 (*c*); $\frac{1}{2}P$, 112 (*r*) and $P\breve{2}$, 122 (*y*).

FIG. 137.—Anglesite Crystal with *m*, *a* and *y* as in Fig. 136. Also $\infty P\breve{\infty}$, 010 (*b*), $P\breve{\infty}$, 011 (*o*); P, 111 (*z*) and $\frac{1}{2}P\bar{\infty}$, 102 (*d*).

reaction for lead. It is distinguished from *cerussite* by the reaction for sulphur and the lack of effervescence with HCl.

Syntheses.—Crystals of anglesite have been made by methods analogous to those used in the preparation of barite crystals.

Occurrence.—The mineral occurs as an alteration product of galena, mainly in the upper portions of veins of lead ores. Under the influence of solutions of carbonates it changes to cerussite.

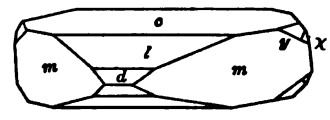


FIG. 138.—Anglesite Crystal with *m*, *y*, *c* and *d* as in Figs. 136 and 137. Also $\frac{1}{4}P\bar{\infty}$, 104 (*l*) and $P\breve{4}$, 144 (x).

Localities.—It is found in Derbyshire and Cumberland, in England; near Siegen, in Prussia; in Australia and in the Sierra Mojada, in Mexico. In the United States crystals occur at Phoenixville, Penn., in the lead districts of the Mississippi Valley, and at various points in the Rocky Mountains.

Uses.—It is mined with other lead compounds as an ore of this metal.

BASIC SULPHATES

Although several basic sulphates are known as minerals, only two are of importance. One, *brochantite*, is a copper compound found, with other copper minerals, in the oxidized portions of ore veins, and the other, *alunite*, is a double salt of aluminium and potassium. This min-

eral is one of a series of compounds forming an isomorphous group, with the general formula $(R'''(OH)_2)_6R'_2(SO_4)_4$ or $(R'''(OH)_2)_6R''(SO_4)_4$, in which $R'''=Al$ or Fe, $R'_2=K_2$, Na_2 or H_2 and $R''=Pb$.

Alunite ($(Al(OH)_2)_6K_2(SO_4)_4$)

Alunite, or alumstone, is a comparatively rare mineral, but, because of its possible utilization as a source of potash, it is of considerable interest. It has long been used abroad as a source of potash alum.

The mineral, when pure, contains 38.6 per cent SO_3, 37.0 per cent Al_2O_3, 11.4 per cent K_2O and 13.0 per cent H_2O, which corresponds to the formula given above, or if written in the form of a double salt $3(Al(OH)_2)_2SO_4 \cdot K_2SO_4$. The chemical composition of a crystalline specimen from Marysville, Utah, is as follows:

SO_3	Al_2O_3	Fe_2O_3	P_2O_5	K_2O	Na_2O	H_2O+	H_2O-	SiO_2	Total
38.34	37.18	tr.	.58	10.46	.33	12.90	.09	.22	100.10

Alunite occurs in hexagonal crystals (ditrigonal scalenohedral class), with an axial ratio of 1 : 1.252. The natural crystals are nearly always simple rhombohedrons, $R(10\bar{1}1)$, or R modified by other rhombohedrons and the basal plane. Because the angle between the rhombohedral faces is about 90° (90° 50′), the habit of the crystals is cubical. The mineral also occurs massive, with fibrous, granular or porcelain-like structure.

Alunite is white, pink, gray or red, and has a white streak. It is transparent or translucent and has a vitreous or nearly pearly luster. Its cleavage is distinct parallel to oP(0001), and it has an uneven, conchoidal or earthy fracture. Its hardness is 3.5–4 and its density= 2.6–2.75. Its indices of refraction for yellow light are: $\epsilon=1.592$, $\omega=1.572$.

Before the blowpipe the mineral decrepitates, but is infusible. In the closed tube it yields water and at a high temperature sulphurous and sulphuric oxides. Heated on charcoal with $Co(NO_3)_2$ it gives the blue color characteristic of Al_2O_3. It also gives the sulphur reaction. It is insoluble in water but is soluble in H_2SO_4. When ignited it gives off all its water and three-quarters of its SO_4, the other quarter remaining in K_2SO_4. When the ignited residue is treated with water, the potassium sulphate dissolves and insoluble Al_2O_3 is left. It is upon this latter reaction that the economic utilization of the mineral depends.

The mineral is characterized by its color and hardness together with the reactions for Al,H_2O and sulphuric acid.

Synthesis.—Crystals have been made by heating an excess of aluminium sulphate with alum and water at 230°.

Occurrence and Origin.—The mineral occurs in seams or veins in acid lavas. It is thought to have been formed in some instances by the action of sulphurous vapors upon the rock forming the vein walls, in other instances by direct precipitation from ascending magmatic waters, and in others by the action of descending H_2SO_4.

Localities.—The principal known occurrences of alunite are at Tolfa, Italy; at Bulla Delah, New South Wales; on Milo, Grecian Archipelago, and at Mt. Dore, France.

In the United States it is found with quartz and kaolin in the Rosita Hills, and the Rico Mts., Colo.; in the ore veins at Silverton and Cripple Creek, Colo.; as a soft white kaolin-like material in the ore veins at Goldfield, Nev.; as a crystalline constituent in the rocks at Goldfield, Nev., and Tres Cerritos, Cal., and in the form of a great vein of comparatively pure material at Marysville, Utah.

Uses.—In Australia alunite is calcined and then heated with dilute sulphuric acid. The mixture is then allowed to settle and the clear solution is drawn off and cooled. Alum crystallizes. The mother liquor which contains aluminium sulphate, after further treatment with the calcined mineral, is evaporated and the aluminium salt separated by crystallization. In the United States it is now (1916) being utilized as a source of potash and aluminium.

Brochantite ($(CuOH)_2SO_4 \cdot 2Cu(OH)_2$) occurs in groups of small prismatic crystals, in fibrous masses and in drusy crusts. Its crystallization is orthorhombic with $a : b : c = .7739 : 1 : .4871$ and the angle $110 \wedge 1\bar{1}0 = 75° 28'$. Cleavage is perfect parallel to $\infty P \breve{\infty}$ (010). The mineral is emerald-green to blackish green and its streak is light green. It is transparent or translucent, and its luster is vitreous, except on cleavage planes where it is slightly pearly. Its hardness is 3.5–4 and density 3.85. In the closed tube it decomposes, yielding water and, at a high temperature, sulphuric acid. It gives the usual reactions for copper and sulphuric acid. Brochantite occurs in the upper portions of copper veins at many places, in some of which it was formed by the interaction between silicates and solutions of copper salts. In the United States it has been found at the Monarch Mine, Chaffee Co., Colorado, at the Mammoth Mine, Tintic District, Utah, and in the Clifton-Morenci Mines, Arizona.

HYDROUS SULPHATES

The hydrous sulphates comprise a number of sulphates combined with water. Among them are the normal salts *mirabilite* or glauber salt ($Na_2SO_4 \cdot 10H_2O$), *gypsum* ($CaSO_4 \cdot 2H_2O$), the *epsomite* and *melanterite* groups ($R''SO_4 \cdot 7H_2O$), *chalcanthite* ($CuSO_4 \cdot 5H_2O$), and the *alum* group ($R'Al(SO_4)_2 \cdot 12H_2O$), *kieserite* ($MgSO_4 \cdot H_2O$), *polyhalite* ($K_2MgCa_2(SO_4)_4 \cdot H_2O$), and a number of basic compounds. Several of them are of considerable economic importance. They are separated into a normal group and a basic group.

HYDRATED NORMAL SULPHATES

The hydrated normal sulphates occur in crystals, and most of them are found also in beds interstratified with other compounds that are known to have been precipitated by the evaporation of sea water or the water of salt and bitter lakes. All are soluble in water.

Mirabilite, or glauber salt, ($Na_2SO_4 \cdot 10H_2O$) is a white, transparent to opaque substance occurring in monoclinic crystals or as efflorescent crusts. Its hardness is 1.5–2 and specific gravity 1.48. It is soluble in water and has a cooling taste. When exposed to the air it loses water and crumbles to a powder. Mirabilite occurs at the hot springs at Karlsbad, Bohemia and is obtained from the water of many of the bitter lakes in California and Nevada. Its crystals are deposited from a pure solution of Na_2SO_4. If the solution contains NaCl, however, thenardite (Na_2SO_4) deposits.

Kieserite ($MgSO_4 \cdot H_2O$) occurs commonly in granular to compact, massive beds interstratified with halite and other soluble salts at Stassfurt, Germany, and at other places where ocean water has been evaporated. It is believed to have resulted from the partial desiccation of epsomite ($MgSO_4 \cdot 7H_2O$), though it may be deposited from a solution of $MgSO_4$ in the presence of $MgCl_2$. Kieserite is white, gray, or yellowish, and is transparent or translucent. It forms sharp bipyramidal monoclinic crystals. Its hardness is 3 and its density 2.57. In the presence of water it passes over into epsomite and dissolves, yielding a solution with a bitter taste. Large quantities are utilized in the fertilizer industry.

When exposed to the air it becomes covered with an opaque crust.

Gypsum ($CaSO_4 \cdot 2H_2O$)

Gypsum is the most important of all the hydrous sulphates. It occurs in massive beds associated with limestone, in crystals, in finely granular aggregates and in fibrous masses, under a great variety of conditions.

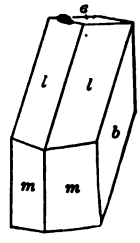
Theoretically, it consists of 46.6 per cent SO_3, 32.5 per cent CaO and 20.9 per cent H_2O, but usually it contains also notable quantities of other components, especially Fe_2O_3, Al_2O_3 and SiO_2. Clay is a common impurity in the massive varieties.

The analyses of two commercial gypsums follow:

	$CaSO_4$	H_2O	SiO_2	Al_2O_3	$CaCO_3$	$MgCO_3$	Total
Dillon, Kans.	78.40	19.96	.35	.12	.56	.57	99.96
Alabaster, Mich.	78.51	20.96	.05	.08	...	.11	99.71

The crystals are monoclinic (prismatic class), with $a : b : c = .6895 : 1 : .4132$ and $\beta = 81° 02'$. They are usually developed with a tabular habit due to the predominance of $\infty P \bar{\infty}$ (010). The prism ∞P(110),

FIG. 139.



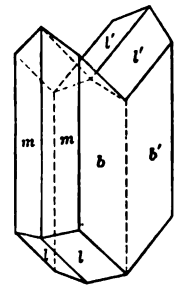


FIG. 140.

FIG. 139.—Gypsum Crystals with ∞P, 110 (m); $\infty P \bar{\infty}$, 010 (b); $-P$, 111 (l) and $\frac{1}{3}P \bar{\infty}$, $\bar{1}03$ (e).

FIG. 140.—Gypsum Twinned about $\infty P \bar{\infty}$ (100). Swallow-tail Twin. Form m, l and b as in Fig. 139.

and pyramid $+P(11\bar{1})$ are also nearly always present (Fig. 139). Often the $+P$ faces are curved, producing a lens-shaped body. Twinning is very common, giving rise to two types of twinned crystals. In the most common of these $\infty P \bar{\infty}$ (100) is the twinning plane and the resulting twin has the form of Fig. 140. In the second type $-P \bar{\infty}$ (101) is the twinning plane (Fig. 141). Forms of this type are frequently bounded by $+P(11\bar{1})$, $-P(111)$, $\frac{1}{3}P \bar{\infty}$ ($\bar{1}03$), and $\infty P \bar{\infty}$ (100). When the side

faces are curved the well known arrowhead twins result (Fig. 141). The angle $110 \wedge 1\bar{1}0 = 68° 30'$.

The mineral possesses a good cleavage parallel to $\infty P \bar{\infty}$ (010) yielding thin inelastic foliae, another parallel to $+P(\bar{1}11)$ and a less perfect one parallel to $\infty P \bar{\infty}$ (100). It is white, colorless and transparent when pure; gray, red, yellow, blue or black when impure. Its hardness is 1.5–2 and sp. gr. = 2.32. The luster of crystals is pearly on $\infty P \bar{\infty}$ (010) and on other surfaces vitreous. Massive varieties are often dull. The refractive indices for yellow light are: $\alpha = 1.5205$, $\beta = 1.5226$, $\gamma = 1.5296$.

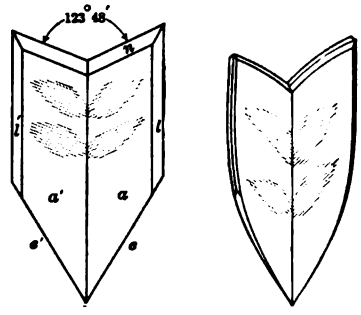


FIG. 141.—Gypsum Twinned about $-P \bar{\infty}$ (101). Forms: $\infty P \bar{\infty}$, 100 (*a*); $-P$, 111 (*l*); P, $11\bar{1}$ (*n*) and $\frac{1}{3} P \bar{\infty}$, $\bar{1}03$ (*e*). Arrow-head Twin.

In the closed tube the mineral gives off water and falls into a white powder (see p. 238). It colors the flame yellowish red and yields the sulphur test on a silver coin. It is soluble in about 450 pts. of water and is readily soluble in HCl. When heated to between 222° F. and 400° F. it loses water and disintegrates into powder, which, when ground, becomes "plaster of Paris." This, when moistened with water, again combines with it and forms gypsum. The crystallization of the mass into an aggregate of interlocking crystals constitutes the "set."

Gypsum is distinguished from other easily cleavable, colorless minerals by its softness and the reactions for S and H_2O.

The varieties of gypsum generally recognized are:

Selenite, the transparent crystallized variety;

Satinspar, a finely fibrous variety;

Alabaster, a fine-grained granular variety, and

Rock-gypsum, a massive, structureless, often impure and colored variety.

Gypsite is gypsum mixed with earth.

Syntheses.—Crystals of gypsum separate from aqueous solutions of $CaSO_4$ at ordinary temperatures, and also from solutions saturated with NaCl and $MgCl_2$. Some of these are twinned.

Occurrence and Origin.—Gypsum forms immense beds interstratified with limestone, clay and salt deposits where it has been precipitated by the evaporation of salt lakes. Its crystals occur around volcanic vents, where they are produced by the action of sulphuric acid on cal-

careous rocks. They are also found isolated in clay and sand, and in limestone, wherever this rock has been acted upon by the sulphuric acid resulting from the weathering of pyrite. Gypsum also occurs in veins and is found in New Mexico in the form of hills of wind-blown sand.

Localities.—Crystals are found in the salt beds at Bex, Switzerland; in the sulphur mines at Girgenti, Sicily, and at Montmartre, France. In the United States they occur at Lockport, N. Y., in Trumbull Co., Ohio, and in Wayne Co., Utah, in limestone; and on the St. Mary's River, Maryland, in clay.

Extensive beds occur in Iowa, Michigan, New York, Virginia, Tennessee, Oklahoma and smaller deposits in many other states, and wind-blown sands in Otero Co., New Mexico.

Uses.—Crude gypsum is used in the manufacture of plaster, as a retarder in Portland cement, and as a fertilizer under the name of land plaster. The calcined mineral is used as plaster of Paris and in the manufacture of various wall finishing plasters, and certain kinds of cements. Small quantities are used in glass factories, and as a white-wash, a deodorizer, to weight phosphatic fertilizer, as an adulterant in candy and other foods, and as a medium for sculpture.

Production.—The quantity of gypsum mined in the United States during 1912 aggregated 2,500,757 tons, valued at $6,563,908 in the form in which it was sold. Of this amount, 441,600 tons of crude material, valued at $623,500 were sold ground, and 1,731,674 tons, valued at $5,940,409, were calcined. The output of New York was valued at $1,241,500, that of Iowa at $845,600 and of Ohio at $812,400.

After the United States the next largest producer is France with a product in 1910 of 1,760,900 tons, valued at $2,942,600 and Canada with 525,246 tons, valued at $934,446.

EPSOMITE AND VITRIOL GROUPS

These groups comprise minerals with the general formula $RSO_4 \cdot 7H_2O$, in which R = Mg, Zn, Fe, Ni, Co, Mn and Cu. Isomorphous mixtures indicate that the compounds are diomorphous, and that the group is, therefore, an isodimorphous group. The group is separable into two divisions, of which one, the *epsomite* group, crystallizes in the bisphenoidal class of the orthorhombic system with axial ratios approximating 1 : 1 : .565. The other division, the *vitriol*, or *melanterite*, group crystallizes in the prismatic class of the monoclinic system with axial ratios approximating 1.18 : 1 : 1.53 and β approximating 75°. Only the magnesium compound among the pure salts is known to crystallize in both systems. Crystals separated from a saturated solution

are orthorhombic, while those separated from a supersaturated solution are monoclinic. Other salts occur in isomorphous mixtures in both systems. All members of the group are soluble in water and all occur as secondary products formed by decomposition of other minerals.

Epsomite ($MgSO_4 \cdot 7H_2O$)

Epsomite, or Epsom salt, usually occurs in botryoidal masses and fibrous crusts coating various rocks over which dilute magnesium sulphate solutions trickle, and mingled with earth in the soils of caves. The solutions result from the action upon magnesian rocks of sulphuric acid derived from oxidizing sulphides. Crystals are rare.

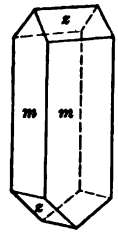


FIG. 142.—Epsomite Crystal with ∞P, 110 (m) and $\frac{P}{2}r$, 111 (z).

The composition corresponding to $MgSO_4 \cdot 7H_2O$ demands 32.5 SO_3, 16.3 MgO and 51.2 H_2O.

The mineral forms white or colorless bisphenoidal, orthorhombic crystals, with an axial ratio $a : b : c = .9901 : 1 : .5709$. Their habit is tetragonal. The angle $110 \wedge 1\bar{1}0 = 89° 26'$. The commonest forms occurring on synthetic crystals are combinations of $\infty P(110)$, and $\frac{P}{2}r(111)$ or $\frac{P}{2}l(1\bar{1}1)$ (Fig. 142). Natural crystals contain, in addition $\infty P\bar{\infty}$ (010) and $P\bar{\infty}$ (101).

The luster of epsomite is vitreous, its hardness 2.0–2.5 and specific gravity 1.70. Its refractive indices for yellow light are: $\alpha = 1.4325$, $\beta = 1.4554$ and $\gamma = 1.4608$.

The mineral is soluble in water, yielding a solution with a bitter taste. With a solution of barium chloride it yields a white precipitate of $BaSO_4$.

Epsomite is distinguished from other colorless, soluble minerals by its taste and the reactions for S and Mg.

Synthesis.—Crystals are produced by evaporation of solutions of $MgSO_4$ containing certain other salts. From those containing borax, crystals of the type indicated above are separated. The production of right or left crystals may be provoked by inoculation of the solution with a particle of a crystal of the desired type.

Localities.—Epsomite occurs in mineral waters, as, for instance, at Seidlitz, Bohemia, on the walls of mines and caves, among the deposits of bitter lakes, and as crystals in the soil covering the floors of caves.

Melanterite, or **copperas** ($FeSO_4 \cdot 7H_2O$), is usually in fibrous, stalactitic or pulverulent masses associated with pyrite or other sulphides containing iron, from which it was produced by weathering processes. It is commonly some shade of green. Its streak is colorless. Its crystals, which are monoclinic (prismatic class), are rare. The mineral has a hardness of 2 and a density of 1.9. It is soluble in water, forming a solution which has a sweetish astringent taste.

ALUM GROUP

The alum group includes a large number of isomorphous compounds with the general formula $R'Al(SO_4)_2 \cdot 12H_2O$. The group crystallizes in the isometric system (dyakisdodecahedral class), but all of its members are so readily soluble in water that they are rarely found in nature. The commonest alums are *kalinite* ($KAl(SO_4)_2 \cdot 12H_2O$) and *soda alum* ($NaAl(SO_4)_2 \cdot 12H_2O$).

DOUBLE SULPHATES WITH CARBONATES OR CHLORIDES

A number of compounds of sulphates with chlorides and carbonates are known, but of these only one is of any great economic importance. Two others afford interesting crystals. The commercial compound is *kainite*, which is a hydrated combination of $MgSO_4$ and KCl, with the formula $MgSO_4 \cdot KCl \cdot 3H_2O$. The other two best known members of the group are *leadhillite* ($PbSO_4 \cdot Pb(PbOH)_2(CO_3)_2$ and *hanksite* ($2Na_2CO_3 \cdot 9Na_2SO_4 \cdot KCl$).

Kainite ($MgSO_4 \cdot KCl \cdot 3H_2O$)

Kainite is found only in beds associated with halite and other deposits from saline waters. It is rarely crystallized. Crystals are monoclinic (prismatic class), with $a : b : c = 1.2186 : 1 : .5863$ and $\beta = 85° 6'$. They possess a pyramidal habit with oP(001) and $\pm P(111)(11\bar{1})$ predominating.

The mineral usually forms granular masses which are white, yellow, gray or red. It is transparent, has a hardness of 2 and sp. gr. 2.13, and is easily soluble in water. Its refractive indices for sodium light are: $\alpha = 1.4948$ and $\gamma = 1.5203$.

When heated in a glass tube it yields water and HCl. It is distinguished from other soluble minerals by this reaction, and by the fact that it yields the test for sulphur, and colors the flame blue when its powder is mixed with CuO and heated before the blowpipe.

Synthesis.—Crystals have been produced by evaporating a solution of K_2SO_4 and $MgSO_4$ containing a great excess of $MgCl_2$.

Occurrence.—Kainite occurs in the salt beds of Stassfurt, Germany, and of Kalusz in Galicia, and in the deposits of salt lakes and lagoons. It also occurs as crusts on some of the lavas of Vesuvius.

Uses.—The mineral is utilized as a source of potassium in the manufacture of potassium salts and fertilizers. Large quantities are imported annually into the United States. In 1912 the imports aggregated 485,132 tons, valued at $2,399,761.

Hanksite ($2Na_2CO_3 \cdot 9Na_2SO_4 \cdot KCl$) occurs almost exclusively in hexagonal prisms that are prismatic or tabular, or in double pyramids suggesting quartz crystals. Their axial ratio is 1 : 1.006. The commonest crystals are bounded by oP(0001), $\infty P(10\bar{1}0)$, $P(10\bar{1}1)$ (Fig. 143) and $2P(20\bar{2}1)$, or $\frac{4}{5}P(40\bar{4}5)$. Their cleavage is imperfect parallel to oP(0001). The mineral is white or yellow. Its hardness = 2 and its specific gravity = 2.56. It is soluble in water. Its refractive indices are: $\omega = 1.4807$ and $\epsilon = 1.4614$. It occurs at Borax Lake and Death Valley, California, in the deposits of salt lakes.

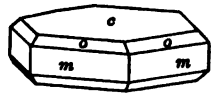


FIG. 143.—Hanksite Crystal with ∞P, $10\bar{1}0$ (*m*); P, $10\bar{1}1$ (*o*) and oP, 0001 (*c*).

Leadhillite ($PbSO_4 \cdot Pb(PbOH)_2(CO_3)_2$) occurs principally as crystals in the oxidized zones of lead and silver veins. The crystals are monoclinic (prismatic class), and have an hexagonal habit. Their axial ratio is 1.7515 : 1 : 2.2261. $\beta = 89°32'$. The principal forms observed on them are oP(001), $\infty P(110)$, $\infty P\bar{\infty}$ (100), P(111) and $\frac{1}{2}P\bar{\infty}$ (102). In the most common twins $\infty P(110)$ is the twinning plane. The mineral is white or yellow, green or gray, and it is transparent or translucent. Its streak is colorless. It is sectile, has a hardness of 2.5 and a specific gravity of 6.35. Before the blowpipe it intumesces, turns yellow, and fuses easily (1.5). Upon cooling it again becomes white. It effervesces in HNO_3 and leaves a white precipitate of $PbSO_4$. It reacts for sulphur and water. It is found at Leadhills, Scotland, and Mattock, England, associated with other ores of lead; at a lead mine near Iglesias, Sardinia, and at several silver-lead mines in Arizona.

CHAPTER XIII

THE CHROMATES, TUNGSTATES AND MOLYBDATES

THE CHROMATES

The only chromate of importance, among minerals, is the lead salt of normal chromic acid, H_2CrO_4. There are several other chromates known, but they are basic salts and are rare. All are lead compounds. The normal salt, $PbCrO_4$, is known as *crocoite*. Chromic acid is unknown, as it spontaneously breaks down into CrO_3 and water when set free from its salts. Its best known compound is potassium chromate, K_2CrO_4.

Crocoite ($PbCrO_4$)

Crocoite is well characterized by its hyacinth-red color. It is a lead chromate with $PbO = 68.9$ per cent and $CrO_3 = 31.1$ per cent.

Its crystallization is monoclinic (prismatic class) with $a : b : c = .9603 : 1 : .9159$ and $\beta = 77° 33'$. Its crystals, which are usually implanted on the walls of cracks in rocks, are prismatic or columnar parallel to $\infty P(110)$. Their predominant forms are $\infty P(110)$, $-P(111)$, and various domes (Fig. 144). Their cleavage is distinct parallel to $\infty P(110)$. The angle $110 \wedge 1\bar{1}0 = 86° 19'$. The mineral also occurs in granular masses.

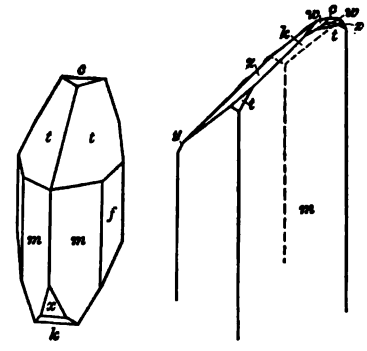


FIG. 144.—Crocoite Crystals with ∞P, 110 (*m*); $\infty P\bar{2}$, 120 (*f*); $-P$, 111 (*t*); $3P\bar{\infty}$, $\bar{3}01$ (*x*); $P\bar{\infty}$, $\bar{1}01$ (*k*); oP, 001 (*c*); $P\breve{\infty}$, 011 (*z*); $2P\breve{\infty}$, 021 (*y*) and $\frac{1}{2}P\breve{\infty}$, 012 (*w*).

Crocoite is bright hyacinth-red, and is translucent. Its streak is orange-yellow. The mineral is sectile. Its fracture is conchoidal, its hardness 2.5–3 and density about 6. Its intermediate refractive index is about 2.42.

In the closed tube it decrepitates, and blackens; but it reassumes its red color when heated. On charcoal it deflagrates and fuses easily,

yielding metallic lead and a lead coating. With microcosmic salt it gives the green bead of chromium.

The mineral is easily recognized by its color and the test for chromium.

Synthesis.—Crystals, like those of crocoite, have been obtained by heating on the water bath a solution of lead nitrate in nitric acid and adding a dilute solution of potassium bichromate.

Occurrence.—Crocoite occurs under conditions which suggest that it is a product of pneumatolysis.

Localities.—It is found in the Urals; at Rezbánya and Moldawa, in Hungary; in Tasmania, and in the Vulture Mining district, Maricopa Co., Arizona.

THE TUNGSTATES AND MOLYBDATES

The tungstates are salts of tungstic acid, H_2WO_4. They are the principal sources of the metal tungsten which is beginning to have important uses. The molybdates are salts of molybdic acid, H_2MoO_4. The two most prominent tungstates are *scheelite*, $CaWO_4$, and *wolframite* $(Fe \cdot Mn)WO_4$, and the most prominent molybdate is *wulfenite*, $PbMoO_4$.

All tungsten compounds give a blue bead with salt of phosphorus in the reducing flame. When fused with Na_2CO_3, dissolved in water and hydrochloric acid, and treated with metallic zinc (see pp. 482, and 492 for details of test), they also yield a blue solution which rapidly changes to brown.

The molybdates give with the salt of phosphorus bead in the oxidizing flame a yellow-green color while hot, changing to colorless when cold. In the reducing flame the color is clear green.

SCHEELITE GROUP

The scheelite group comprises a series of tungstates and molybdates of Ca, Cu and Pb. The minerals are tetragonal and hemihedral and are all well crystallized. The more important members of the group are *scheelite* and *wulfenite*. *Cuprotungstite* is a copper tungstate ($CuWO_4$) and *stolzite* a lead tungstate ($PbWO_4$).

Scheelite ($CaWO_4$)

The formula of scheelite demands 80.6 per cent WO_3, and 19.4 per cent CaO, but the mineral usually contains a little molybdenum in place of some of the tungsten. It nearly always contains also a little Fe.

Scheelite crystallizes in the tetragonal bipyramidal class. Its crystals are usually pyramidal, though often tabular in habit. Their axial ratio is 1 : 1.5268. On the pyramidal types the predominant planes are pyramids of the first, second (Fig. 145), and third orders and on the tabular types, in addition, the basal plane. One of the most familiar combinations is P(111), P∞ (101), $\left[\frac{P3}{2}\right]$(313) and $\left[\frac{3P3}{2}\right]$(131) (Fig. 145). Other forms frequently found on its crystals are ½P∞ (102) and ⅕P∞ (105). The angle $110 \wedge \bar{1}11 = 79° \; 55\frac{1}{2}'$. Twinning is common, both contact and penetration twins having ∞P∞ (100) as the twinning plane. The mineral also occurs in reniform and granular masses.

Scheelite is white, yellow, brown, greenish or reddish, with a white

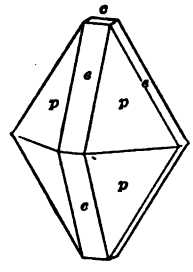


FIG. 145.

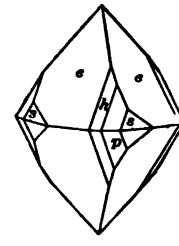


FIG. 146.

FIG. 145.—Scheelite Crystal with P, 111 (*p*); P∞, 101 (*e*) and oP, 001 (*c*).

FIG. 146.—Scheelite Crystal with *p* and *e* as in Fig. 145. Also $\left[\frac{P3}{2}\right]$, 313 (*h*) and $\left[\frac{3P3}{2}\right]$, 131 (*s*).

streak and vitreous luster. It has a distinct cleavage parallel to P(001), and an uneven fracture. It is brittle, has a hardness of 4.5–5 and a density of about 6, and is transparent or translucent. It is soluble in HCl and HNO_3 with the production of a yellow powder, tungsten trioxide, which is soluble in ammonia. Its refractive indices are: $\epsilon = 1.9345$, $\omega = 1.9185$ for red light.

Before the blowpipe the mineral fuses to a semitransparent glass. With borax it forms a transparent glass which becomes opaque on cooling. With salt of phosphorus it yields the characteristic beads for tungsten, but specimens containing iron must be heated with tin on charcoal before the blue color can be developed.

Scheelite is distinguished from *limestone*, which its massive forms closely resemble, by its higher specific gravity and the absence of effer-

vescence with HCl. From *quartz* it is distinguished by its softness and from *barite* by greater hardness and higher specific gravity.

Syntheses.—Crystals of scheelite have been made by adding a solution of sodium tungstate to a hot acid solution of $CaCl_2$, and by fusing the two compounds. They have also been produced by fusing wolframite with $CaCl_2$.

Occurrence and Origin.—Scheelite is found in gold-quartz veins and in veins cutting acid igneous rocks, where it is associated with cassiterite, topaz, fluorite, molybdenite, wolframite and many other metallic compounds, and as a contact metamorphic product in altered limestone intruded by granite. It is probably in all cases a deposit from hot solutions.

Localities.—It occurs at Zinnwald, Bohemia; Altenberg, Saxony; Carrock Fells, Cumberland, England; Pitkäranta, Finland; in New Zealand; and in the United States at Monroe and Trumbull, Conn.; in the Atolia District, Kern Co., California; the Mammoth Mining District, Nevada; in Lake County, Colorado; near Gage, New Mexico, where it occurs with pyrite and galena in a vein cutting limestone, and in the placer gravels at Nome, Alaska.

Uses of Tungsten.—Tungsten is used principally in the manufacture of tool steel, electric furnaces and targets for Röntgen rays. It is employed also as filaments in electric-light bulbs, in the manufacture of sodium tungstate which is used for fireproofing cloth, as a mordant in dyeing, and for a number of other minor purposes.

Production.—Scheelite has been mined in small quantity in Idaho, Alaska, California, Nevada, Arizona, and New Mexico, as a source of tungsten, but most of this element has heretofore been produced from other compounds, mainly wolframite. In 1913 a few hundred tons of scheelite concentrates were produced in the Atolia district, California, and the Old Hat district, near Tucson, Ariz. At present (1916) it is being produced in large quantity near Bishop, Inyo Co., Cal.

Stolzite ($PbWO_4$) is completely isomorphous with wulfenite. Its crystals, which are pyramidal or short columnar, are mainly combinations of $\infty P(110)$, $P(111)$, $2P(221)$ and $oP(001)$. Their axial ratio is $1 : 1.5606$.

The mineral is gray, brown, green or red. It is translucent and has a white streak. Its hardness is 2.75–3 and its sp. gr. 7.87–8.23. Its refractive indices for yellow light are: $\omega = 2.2685$, $\epsilon = 2.182$.

Before the blowpipe it decrepitates and melts to a lustrous crystalline globule. The bead with microcosmic salt in the reducing flame

is blue when cold; in the oxidizing flame it is colorless. The mineral is decomposed by HNO_3 leaving a yellow residue of WO_3. Crystals have been made by fusing sodium tungstate and lead chloride.

Its principal localities are the tin-bearing veins at Zinnwald, Bohemia; the copper veins in Coquimbo, Chile; and Southampton, Mass., where it is associated with other lead compounds.

Wulfenite ($PbMoO_4$)

Wulfenite is the only molybdate of importance that occurs as a mineral. Its formula demands 39.3 MoO_3 and 60.7 PbO. Calcium sometimes replaces a part of the Pb and tungsten a part of the Mo.

Wulfenite is hemihedral and hemimorphic (tetragonal pyramidal class). Its crystals are more frequently tabular than those of scheelite, and they are usually very thin.

The mineral, however, occurs also in pyramidal and prismatic crystals which, in some cases, exhibit distinct hemimorphism. Their axial

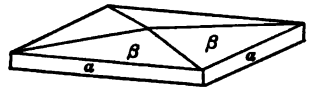


FIG. 147.

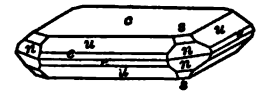


FIG. 148.

FIG. 147.—Wulfenite Crystal with $\infty P\infty$, 100 (a) and $\frac{1}{12}P\infty$, 1.0.12 (β).
FIG. 148.—Wulfenite Crystal with oP, 001 (c); $\frac{1}{2}P\infty$, 102 (u); $P\infty$, 101 (e); P, 111 (n) and $\frac{1}{3}P$, 113 (s).

ratio is $a : c = 1 : 1.5777$. The most common forms found on its crystals are: oP(001), P(111), $\left[\frac{\infty P\frac{3}{2}}{2}\right]$(320), $\frac{1}{3}$P(113) and $P\infty$ (101) (Fig. 147 and 148). The angle $111 \wedge \bar{1}11 = 80° 22'$.

The cleavage, parallel to P, is very smooth, and the fracture is conchoidal. The mineral is brittle. Its hardness is about 3 and specific gravity about 6.8. Its luster is resinous or adamantine, and its color orange-yellow, olive-green, gray, brown, bright red or colorless. Its streak is white and it is transparent. For red light, $\omega = 2.402$, $\epsilon = 2.304$.

Before the blowpipe wulfenite decrepitates and fuses readily. With salt of phosphorus it gives the molybdenum beads. With soda on charcoal it yields a lead globule. When the powdered mineral is evaporated with HCl molybdic oxide is formed. On moistening this with water and adding metallic zinc an intense blue color is produced.

Wulfenite is distinguished from *vanadinite* (p. 271), by crystallization, by the test for chlorine (vanadinite) and the test for tungsten.

Synthesis.—Wulfenite crystals have been produced by melting together sodium molybdate and lead chloride.

Occurrence and Localities.—The mineral occurs in the oxidized zone of veins of lead ores at some of the principal lead occurrences in Europe, and in the United States near Phoenixville, Pennsylvania; in the Organ Mountains, New Mexico; at the mines in Yuma County, Arizona; at the Mammoth Mine, in Pinal County in the same State, and at many other of the lead mines in the Rocky Mountain states.

Uses.—Wulfenite is an important source of molybdenum, but, because of the few uses to which this metal is put, the amount of wulfenite mined annually is very small.

WOLFRAMITE GROUP

Wolframite ($(Fe \cdot Mn)WO_4$)

Wolframite is the name given the isomorphous mixture of the manganese and iron tungstates that occur nearly pure in some varieties of the minerals *hübnerite* and *ferberite.*

The mixture of the iron and manganese molecules is more common than either alone, consequently wolframite is the commonest member of the group. The properties of all three minerals, however, are so nearly alike that they must be distinguished by chemical analysis.

The name wolframite is usually applied to mixtures of the tungstates in which the proportion of Fe to Mn varies between 4 : 1 and 2 : 3, or between 9.5 per cent and 18.9 per cent of FeO and 14 per cent and 4.7 per cent of MnO_2.

It has recently been suggested that the name ferberite be limited to mixtures containing not more than 20 per cent of the hübnerite molecule and the name hübnerite to those containing not more than 20 per cent of the ferberite molecule. This would leave the name wolframite for mixtures containing more than 20 per cent of both $FeWO_4$ and $MnWO_4$.

Analyses of specimens of hübnerite (I), wolframite (II and III) and ferberite (IV) follow:

	WO_3	FeO	MnO	CaO	Other	Total
I. Ellsworth, Nye Co., Nev...	74.88	.56	23.87	.14	.16	99.61
II. Sierra Cordoba, Argentine..	74.86	13.45	11.02	...	1.22	100.55
III. Cabarrus Co., N. C.....	75.79	19.80	5.35	.32	tr	101.26
IV. Kimbosan, Japan.....	75.47	24.33	....	tr	tr	99.80

All members of the group crystallize in the monoclinic system (prismatic class) with axial ratios as follows:

Ferberite	$a : b : c = .8229 : 1 : .8463.$	$\beta = 89° 38'$
Wolframite	$= .8300 : 1 : .8678.$	$\beta = 89° 38'$
Hübnerite	$= .8315 : 1 : .8651.$	$\beta = 89° 38'$

The crystals are prismatic or cubic in habit and are bounded by $\infty P(110)$, $\infty P\bar{\infty}(100)$, and two or more of the following: $oP(001)$, $\infty P\breve{\infty}(010)$, $\infty P\bar{2}(210)$, $P\breve{\infty}(011)$, $\frac{1}{2}P\bar{\infty}(\bar{1}02)$, $-\frac{1}{2}P\bar{\infty}(102)$, $-P(111)$, $-2P\bar{2}(121)$ and $+2P\infty(10\bar{2})$ (Fig. 149). The angle $110 \wedge 1\bar{1}0$ for ferberite $= 78° 51'$, for wolframite $79° 23'$, and for hübnerite $79° 29'$. Twins are fairly common, with $\infty P\bar{\infty}(100)$ the twinning plane. Cleavage is perfect parallel to $\infty P\breve{\infty}(010)$. The minerals also occur in lamellar and granular masses.

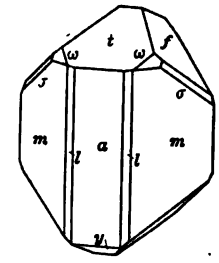


FIG. 149.—Wolframite Crystal with ∞P, 110 (*m*); $\infty P\bar{2}$, 210 (*l*); $\infty P\bar{\infty}$, 100 (*a*); $-\frac{1}{2}P\bar{\infty}$, 102 (*t*); $P\breve{\infty}$, 011 (*f*); $-2P\bar{2}$, 121 (*σ*); $+\frac{1}{2}P\bar{\infty}$, $10\bar{2}$ (*y*) and $-P$, 111 (*w*).

Hübnerite is brownish red to black and translucent, wolframite is black and translucent only on thin edges, and ferberite is black and opaque. The streak is yellow to yellowish brown in hübnerite and brown or brownish black in ferberite, with the streak of wolframite between.

Wolframite is brittle, has a hardness of 5–5.5, a specific gravity of 7.2–7.5, and a submetallic luster. Before the blowpipe it fuses to a globule which is magnetic. Fused with soda and niter on platinum it gives the bluish green manganate. The salt of phosphorus bead is reddish yellow when hot and a paler tint when cold. In the reducing flame the bead becomes dark red. If the mineral is treated first on charcoal with tin its bead assumes a green color on cooling. The mineral dissolves in aqua regia with the production of the yellow tungsten trioxide. When treated with concentrated H_2SO_4 and zinc it yields the blue tungsten reaction.

Crystals of wolframite are easily distinguished from crystallized *columbite* (p. 293), *samarskite* (p. 295), and *uraninite* (p. 297), by differences in crystallization. Massive wolframite is distinguished from massive forms of the other three minerals by its more perfect cleavage and by the reactions with the beads. Uraninite, moreover, contains lead. Wolframite is distinguished from black *tourmaline* (p. 434) by the differences in specific gravity.

Occurrence and Origin.—Wolframite usually occurs in veins with tin ores, and in quartz veins with various sulphides, and in pegmatite. Its origin is probably pneumatolytic.

Localities.—Wolframite is found in all tin-producing districts, especially at Zinnwald, Schneeberg and Freiberg, in Germany; at Nerchinsk, in Siberia; in Cornwall, England; at Oruro, in Bolivia, and at various points in New South Wales, Australia.

In the United States it occurs at Monroe, Conn.; near Mine La Motte, Missouri; near Lead, South Dakota, where it impregnates a sandy dolomite, and at Hill City in the same State in quartz veins, sometimes containing cassiterite; in Boulder Co., Colorado, in veins in granite (ferberite); near Butte, Montana, in quartz veins carrying silver ores (hübnerite); and the quartz-cassiterite veins near Nome and on Bonanza Creek, in Alaska; and in quartz veins at various points in Washington, Idaho, California, Nevada, New Mexico and Arizona. At some of these localities the mineral is more properly hübnerite.

One or another of the three has been mined in Colorado, Nevada, South Dakota, Montana, Washington, California, Arizona, and New Mexico, but the total production has never been large. Some of the ore shipped has been obtained from placers along streams that drain regions containing the mineral in veins, but most of it has been obtained from vein rock which is crushed and concentrated.

Uses.—These three minerals constitute the principal source of tungsten used in the arts. The uses of the metal are referred to under scheelite.

Production.—The total production of concentrates containing 60 per cent WO_3 in the United States during 1913 was 1,525 tons, valued at $640,500. Of this, 953 tons were ferberite from Boulder Co., Colorado. A little hübnerite was produced in the Arivica region, in southeast California, at Dragoon, Arizona, at Round Mountain, Nevada, and on Paterson Creek, Idaho. In addition, there were imported $86,000 worth of tungsten-bearing ores and $143,800 worth of tungsten metal and ferro-tungsten. The world's production of tungsten ore in 1912 was 9,115 tons.

CHAPTER XIV

THE PHOSPHATES, ARSENATES AND VANADATES

THE phosphates are salts of phosphoric acid, H_3PO_4, the arsenates of the corresponding arsenic acid, H_3AsO_4, and the vanadates of the corresponding vanadic acid, H_3VO_4. The phosphates are by far the most important as minerals. They are easily distinguished by yielding phosphine, H_3P, upon igniting with metallic magnesium and moistening the resulting Mg_3P_2 with H_2O or HCl ($Mg_3P_2+6HCl=3MgCl_2+2PH_3$). The gas is recognized by its disagreeable odor. The arsenates are detected by the test for arsenic.

The arsenates, phosphates and vanadates form groups of isomorphous compounds, the most important of which is the apatite group. Those occurring as minerals are divisible into several subgroups, of which the following six contain common minerals, viz.: (1) anhydrous (*a*) normal salts, (*b*) basic salts and (*c*) acid salts, and (2) hydrous (*a*) normal salts, (*b*) basic salts and (*c*) acid salts.

A number of the phosphates and arsenates are of value commercially either because of the phosphorus they contain; because they are sources of valuable metallic salts; because they serve to indicate the presence of other valuable compounds; or because they possess an ornamental character.

Nearly all the phosphates are transparent or translucent and all are nonconductors of electricity or are very poor conductors.

ANHYDROUS PHOSPHATES, ARSENATES AND VANADATES

NORMAL PHOSPHATES, ARSENATES AND VANADATES

The minerals belonging in this class of compounds are not as numerous as the basic salts, but some of them are of great value. The class includes phosphates of yttrium, the alkalies, beryllium, cerium, magnesium, iron and manganese and a group of isomorphous phosphates, arsenates and vanadates—the apatite group—in which a haloid radicle replaces one of the hydrogen atoms of the acids. *Apatite*, the principal member of the group, is an important source of phosphoric acid.

Triphylite—($Li(Mn \cdot Fe)PO_4$)—Lithiophilite

Triphylite is the name usually applied to the isomorphous mixture of $LiFePO_4$ and $LiMnPO_4$, in which the manganese molecule is present in small quantity only. The mixture containing a large excess of the manganese molecule is called *lithiophilite.*

The pure triphylite molecule contains $FeO = 45.5$ per cent, $Li_2O = 9.5$ per cent and $P_2O_5 = 45$ per cent. The pure lithiophilite molecule consists of 45.1 per cent MnO, 9.6 per cent Li_2O and 45.3 per cent P_2O_5.

Both substances are orthorhombic (bipyramidal class), with an axial ratio approximating .4348 : 1 : 5265. Crystals are rare and not well developed. They are usually rough prisms bounded by $\infty P \breve{\infty}$ (010), oP(001), ∞P(110), $\infty P\breve{2}$(120) and $2P\breve{\infty}$ (021). The minerals usually occur massive, or in irregular, rounded crystals, with two very distinct cleavages.

Both minerals are transparent to translucent, both have a white streak, and both are vitreous to resinous in luster. Their hardness is about 4.5–5 and sp. gr. about 3.5. Triphylite is greenish gray to blue, and lithiophilite pink, yellow or brown. The refractive indices for light brown lithiophilite are: $\alpha = 1.676$, $\beta = 1.679$, $\gamma = 1.687$; those for blue triphylite are a trifle higher.

When heated in closed tubes both compounds are apt to turn dark. They fuse at a low temperature (1.5) and color the flame crimson. In the case of triphylite the crimson streak is bordered by the green of iron. Lithiophilite gives the reactions for Mn. Most specimens give reactions for all these metals—Fe, Mn and Li. Both minerals are soluble in HCl.

The two minerals are distinguished from other compounds by their reactions for phosphorus and lithium, and from each other by the reactions for Fe and Mn.

Occurrence.—They usually occur as primary constituents of coarse granite veins. They are associated with beryl, tourmaline and other pneumatolytic minerals and with secondary phosphates, which are presumably weathering products of the primary phosphates.

Localities.—Both minerals occur at a number of points associated with other lithium compounds, especially spodumene (p. 378). In this country triphylite has been found at Peru, Maine; Grafton, New Hampshire, and Norwich, Massachusetts; lithiophilite at Branchville, Connecticut, and at Norway, Maine.

Neither of the minerals possesses a commercial value at present.

Beryllonite ($NaBePO_4$)

Beryllonite is a comparatively rare mineral occurring at only a few places and always in crystals or in crystalline grains.

Its composition is 24.4 per cent Na_2O, 19.7 per cent BeO and 55.9 per cent P_2O_5.

Its crystals are orthorhombic (bipyramidal class), with an axial ratio .5724 : 1 : .5490. They are short pyramidal or tabular in habit, often exhibiting a pseudohexagonal symmetry. Most crystals are highly modified with oP(001), $\infty P\bar{\infty}$ (100), $\infty P\breve{\infty}$ (010), $P\bar{\infty}$ (101) and $2P\breve{2}$(121), the principal forms. Twins are common, with ∞P(110) the twinning plane. The crystal faces are frequently strongly etched.

The mineral is white to pale yellow. It has a vitreous luster, except on oP(001), where the luster is sometimes pearly. It possesses four cleavages, of which the most perfect is parallel to oP(001). That parallel to $\infty P\bar{\infty}$ (100) is distinct, but the others are indistinct. Its hardness is 5.5–6 and its density 2.845. Its fracture is conchoidal. Crystals often contain numerous inclusions of water and liquid CO_2 arranged in lines parallel to *c*. Its refractive indices for yellow light are: $\alpha = 1.5520$, $\beta = 1.5579$, $\gamma = 1.5608$.

Beryllonite decrepitates and fuses in the blowpipe flame to a cloudy glass, at the same time imparting to the flame a yellow color. It is slowly soluble in HCl, and gives the phosphorus reaction with magnesium.

It is distinguished from most other colorless transparent minerals by the reaction for phosphorus; from other colorless phosphates by its crystallization and the sodium flame test.

Occurrence and Localities.—The best known occurrence of beryllonite in the United States is Stoneham, Maine, where it is found in the debris of a pegmatite dike associated with apatite (p. 266), beryl (p. 359), and other common constituents of pegmatites. It originally existed implanted on the walls of cavities in the pegmatite and was apparently the result of pneumatolytic processes.

Use.—The mineral is used to some extent as a gem stone.

Monazite ($(Ce \cdot Di \cdot La)PO_4$)

Monazite is the principal source of certain rare earths that are used in manufacturing gas mantles. Although it occurs as small grains and crystals in certain granites it is found in commercial quantities only in the sands of streams.

The mineral is a phosphate of the metals cerium, lanthanum, praseodidymium and neodidymium in most cases combined with the silicate of thorium. Its composition may be represented by the formula

$$x((Ce \cdot La \cdot Di)PO_4)+y(ThSiO_4),$$

in which the proportion of the second constituent varies from a trace to an amount yielding 20 per cent ThO_2. Since this is not constant in quantity it is not to be regarded as an essential portion of the compound. It is probable that in monazite we have to do with a solid solution of cerium and thorium phosphates, thorium silicate and oxides of the rare metals.

Monazite is monoclinic with $a : b : c = .9693 : 1 : .9255$ and $\beta = 76° 20'$. Crystals are usually prismatic with the pinacoids $\infty P \bar{\infty}$ (100), $\infty P \breve{\infty}$ (010), the prism ∞P(110), the two domes $-P \bar{\infty}$ (101) and $+P \bar{\infty}$ ($10\bar{1}$) and the pyramids $-P$(111) and $+P$($11\bar{1}$). They are often flattened parallel to the orthopinacoid (Fig. 150). The angle $110 \wedge 1\bar{1}0 = 86° 34'$.

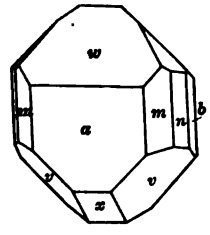


FIG. 150.—Monazite Crystal with $\infty P \bar{\infty}$, 100 (*a*); ∞P, 110 (*m*); $\infty P\bar{2}$, 120 (*u*); $\infty P \breve{\infty}$, 010 (*b*); $-P \bar{\infty}$, 101 (*w*); $+P \bar{\infty}$, $10\bar{1}$ (*x*) and P, $11\bar{1}$ (*v*).

Their cleavage is perfect parallel to oP. The color of the mineral is gray, yellow, reddish, brown or green. It is usually transparent or translucent and sometimes opaque. It is brittle, has a white streak, and a resinous luster. Its hardness is 5–5.5 and its sp. gr. 4.7–5.3, varying with the proportion of thorium present. The refractive indices for yellow light are: $\alpha = 1.7938$, $\gamma = 1.8452$.

The mineral is infusible. Before the blowpipe it turns gray, and when moistened with H_2SO_4 it colors the flame bluish green. It is difficultly soluble in HCl and HNO_3. Most specimens are strongly radioactive.

Synthesis.—Crystals of monazite have not been prepared, but crystals of cerium phosphate similar to those of monazite have been made by heating to redness a mixture of cerium phosphate and cerium chloride.

Occurrence and Origin.—Monazite occurs as the constituent of certain granites and granitic schists in small crystals scattered among the other components. In this form it is a separation from the granitic magma. When the granites are broken down to sand by weathering the monazite is freed and because of its specific gravity it concentrates in stream channels.

Localities.—Although the mineral is fairly widespread in the rocks,

it is concentrated into commercial deposits at only a few places. The most important of these are in southeastern Brazil, in Norway, and in a belt 20 to 30 miles wide and 150 miles long extending along the east side of the Appalachian Mountains from North Carolina into South Carolina.

The mineral has also been reported from many points in ten counties in Idaho. Near Centerville it may be in sufficient quantity to be of commercial importance.

Preparation.—Monazite is separated from the valueless sand in which it is found, by washing, and the residues thus resulting are further concentrated by a magnetic process. The commercial concentrates produced in this way usually contain from 3 to 9 per cent ThO_2, and their price varies accordingly.

Production and Uses.—Monazite is the chief source of thorium oxide used in the manufacture of incandescent gas mantles. Formerly it was produced in large quantity in the Carolinas, the production in 1909 amounting to 542,000 lb., valued at $65,032, and in 1905 to 1,352,418 lb., valued at $163,908. All of this was manufactured into the nitrate of thorium in this country and the amount made was not sufficient to meet the domestic demand. Consequently, large quantities of the nitrate were imported. In 1910–11 mining of the mineral in the Carolinas ceased and all the monazite needed has been imported since then. The imports of thorium nitrate for 1912 were 117,485 lb., valued at $225,386 and of monazite, an amount valued at $47,334.

Xenotime (YPO_4)

Xenotime, though essentially an yttrium phosphate, usually contains erbium and in some cases cerium. It occurs in tetragonal crystals and in rolled grains. Its axial ratio is 1 : .6177 and the angle $111 \wedge 1\bar{1}1 = 55° 30'$. Its crystals are octahedral or prismatic and are bounded by ∞ P(110), P(111), and in some cases by ∞ P ∞ (100) and 2P ∞ (201) (Fig. 151). Their cleavage is perfect parallel to ∞ P(110). The mineral is brown, pink, gray or yellow. Its streak is a pale shade of the same color. It is opaque and brittle. Its luster is vitreous or resinous; its hardness 4–5 and specific gravity 4.5. Its indices of refraction are: $\epsilon = 1.81$, $\omega = 1.72$.

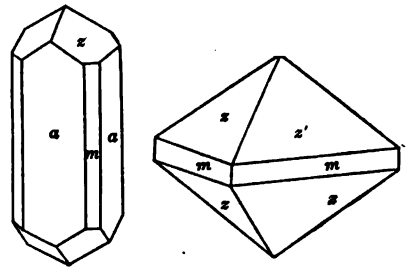


FIG. 151.—Xenotime Crystals with ∞ P, 110 (*m*), P. 111 (*z*), and ∞ P ∞; 100 (*a*).

Xenotime is infusible, insoluble in acids and with difficulty soluble in molten microcosmic salt. It is distinguished from *zircon* by its cleavage and inferior hardness.

A variety of xenotime containing a small percentage of sulphates is known as *hussakite*.

The mineral occurs in pegmatite veins, in granites and in the sands of streams. It is found in pegmatite veins at Hittero, Moss, and other places in Norway; at Ytterby, Sweden; in the granites of Minas Geraes, Brazil, and in the gold washings at Clarksville, Georgia, and many places in North Carolina, and in pegmatite veins in Alexander County in the same State.

APATITE GROUP

The apatite group consists of a number of phosphates, arsenates and vanadates in which fluorine or chlorine takes the place of the hydroxyl in basic compounds. Thus, *fluorapatite* is $Ca_4(CaF)(PO_4)_3$ and *chlorapatite* $Ca_4(CaCl)(PO_4)_3$. The group contains a number of important minerals, of which *apatite* is by far the most valuable. These minerals are isomorphous, all crystallizing in the hemihedral division of the hexagonal system (hexagonal bipyramidal class). The names, compositions and axial ratios of the most important are as follows:

Fluorapatite	$Ca_4(CaF)(PO_4)_3$	$a : c = 1 : .7346$
Chlorapatite	$Ca_4(CaCl)(PO_4)_3$	$a : c = 1 : .7346+$
Pyromorphite	$Pb_4(PbCl)(PO_4)_3$	$a : c = 1 : .7293$
Mimetite	$Pb_4(PbCl)(AsO_4)_3$	$a : c = 1 : .7315$
Vanadinite	$Pb_4(PbCl)(VO_4)_3$	$a : c = 1 : .7122$

Apatite ($Ca_4(Ca(F \cdot Cl))(PO_4)_3$)

Although fluorapatite and chlorapatite are distinct compounds with slightly different properties, nevertheless, because of the difficulty of discriminating between them without analyses, the name apatite is commonly applied to both. This is justified because of the fact that the two compounds are completely isomorphous, and the mineral as it usually occurs is a mixture of both. The ideal molecules comprising the two varieties of apatite have the following compositions:

Fluorapatite	$CaO = 55.5$, $F = 3.8$, $P_2O_5 = 42.3$
Chlorapatite	$CaO = 53.8$, $Cl = 6.8$, $P_2O_5 = 41.0$

Apatite is found in well defined crystals, sometimes very large. These have a holohedral habit, but etch figures on their basal planes

reveal the grade of symmetry of pyramidal hemihedrism. The mineral occurs also massive, in granular and fibrous aggregates and less commonly in globular forms and as crusts.

The crystals are usually columnar or tabular, with the hexagonal prism or pyramid well developed. Although in some cases highly modified, most crystals contain only the $\infty P(10\bar{1}0)$, $P(10\bar{1}1)$ and $oP(0001)$ planes prominent, though $\frac{1}{2}P(10\bar{1}2)$ and $2P2(11\bar{2}1)$ are not uncommon as small faces (Figs. 152 and 153). Their cleavage is indistinct, and their fracture often conchoidal.

Apatite may possess almost any color. In a few cases the mineral is colorless or amethystine and transparent, but in most cases it is translucent or opaque and white, green, bluish, brown or red. Its streak is

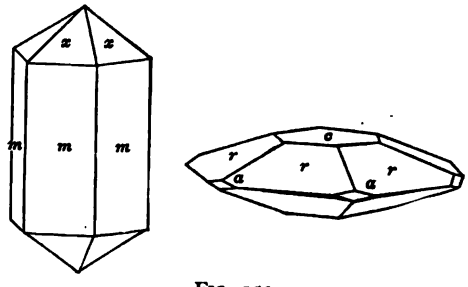


FIG. 152.

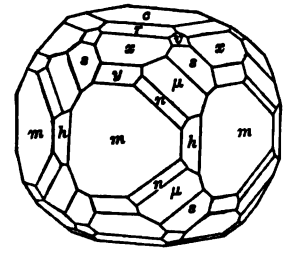


FIG. 153.

FIG. 152.—Apatite Crystals with ∞P, $10\bar{1}0$ (m); P, $10\bar{1}1$ (x); oP, 0001 (c); $\frac{1}{2}P$, $10\bar{1}2$ (r) and $\infty P2$, $11\bar{2}0$ (a).

FIG. 153.—Apatite Crystal with m, x, r and c as in Fig. 152 and $2P$, $20\bar{2}1$ (y); $4P\frac{4}{3}$, $13\bar{4}1$ (n); $3P\frac{3}{2}$, $12\bar{3}1$ (μ); $2P2$, $11\bar{2}1$ (s); $P2$, $11\bar{2}2$ (v) and $\infty P\frac{3}{2}$, $12\bar{3}0$ (h).

white and its luster vitreous to resinous. Its hardness is 4.5–5 and sp. gr. between 3.09 and 3.39. The refractive indices of fluorapatite for yellow light are: $\omega = 1.6335$, $\epsilon = 1.6316$ and of chlorapatite, $\omega = 1.6667$. Many specimens are distinctly phosphorescent. Nearly all fluoresce in yellowish green tints, and all are thermo-electric.

Apatite fuses with difficulty, tinging the flame reddish yellow. The chlorapatite melts at 1530° and the fluorine variety at 1650°. When moistened with H_2SO_4 all varieties color the flame pale bluish green, due to the phosphoric acid. Specimens containing chlorine give the brilliant blue color to the flame when fused in a bead of microcosmic salt that has been saturated with copper oxide. Specimens containing fluorine etch glass when fused with this salt in an open glass tube. The mineral also yields phosphine when ignited with magnesium, and it dissolves in HCl and HNO_3.

Apatite is much softer than *beryl* (p. 359), which it closely resembles in appearance. It is distinguished from *calcite* by lack of effervescence with acids and from other compounds by the phosphorus reaction.

The varieties of the mineral recognized by distinct names are:

Ordinary apatite, crystals or granular masses.

Manganapatite, in which manganese partly replaces the Ca of ordinary apatite. This is dark bluish green.

Fibrous, concretionary apatite. Known also as *phosphorite.*

Osteolite. The earthy variety.

Phosphate rock. A mixture of apatite, phosphorite, several hydrous carbonates and phosphates of calcium, and fragments of bone and teeth. It is more properly a rock with a brecciated and concretionary structure. The composition of typical deposits is represented by the following analysis of hard rock phosphate from South Carolina:

CaO	P_2O_5	CO_2	Fe_2O_3	Al_2O_3	MgO	Insol.	Undet.	H_2O	Moist.
50.08	38.84	.65	.96	3.07	.30	.49	2.46	2.96	.07

Guano is a mixture of various phosphates, both hydrous and anhydrous, calcite and a number of other compounds. It is rather a rock than a mineral, as it has no definite composition.

Syntheses.—Crystals of fluorapatite have been made by fusing sodium phosphate with CaF_2 and by heating calcium phosphate with a mixture of KF and KCl.

Origin.—The crystallized apatite was formed by direct separation from igneous rock magmas and by pneumatolytic action upon limestone. The phosphorite variety and the phosphate in phosphate rock were probably produced by the solution of calcium phosphate and its later deposition from solution—the original phosphate having been furnished in many cases by the shells of mollusca, and by the action of phosphoric acid produced by the decay of organisms upon limestone. In many cases phosphorite accumulated as a residual deposit in consequence of the solution of the calcite and dolomite from phosphatic limestone, leaving the less soluble phosphate as a mantle on the surface.

Occurrence.—The mineral occurs in microscopic crystals as a component of many rocks, as large crystals in metamorphosed limestones, as a component of many coarse-grained veins, especially those composed of coarse granite and those in which cassiterite, magnetite, tourmaline, and other pneumatolytic minerals are found. At a number of places aggregates of apatite and magnetite or ilmenite occur in such large masses as to be worthy of being called rocks. An impure apatite in concretionary and fibrous forms also occurs in thin beds covering large

areas. It is often mixed with other phosphates, with the bones and teeth of animals and with other impurities. This is the well known phosphate rock or phosphorite.

Localities.—Crystallized apatite is so widely spread that it is useless to mention its occurrences. It is mined at Kragerö and near Bamle, in Norway; at various points in Ottawa County in Quebec, and in Frontenac, Lanark and Leeds Counties in Ontario; and at Mineville, New York. Rock phosphate is found in extensive beds on the west side of the peninsula of Florida, in South Carolina, North Carolina, Alabama, Tennessee, Wyoming, Idaho, Utah and Arkansas. A mixture of apatite and ilmenite (*nelsonite*), occurs as dikes in Nelson and Roanoke Counties, Virginia.

Uses.—The principal use of apatite and phosphate rock is in the manufacture of fertilizers. The rock (or crushed apatite) is treated with H_2SO_4 to make an acid phosphate which is soluble in water. Ammonia or potash, or both, are added to the mass and the compound is sold as a superphosphate. The purest varieties are treated with H_2SO_4 in sufficient quantity to entirely decompose them, $CaSO_4$ and H_3PO_4 being formed. The latter is drawn off and mixed with additional high-grade rock and the mixture is known as concentrated phosphate. Superphosphates are manufactured in large quantities in the United States and the concentrated phosphates in Europe. Unfortunately, for the latter use the best grades of apatite or rock phosphate are required, and consequently the best grades of rock produced in the United States are exported and thus lost to American farmers.

Production.—The world's production of apatite and phosphate rock during 1912 was as follows:

United States.....	3,020,905 tons, valued at	$11,675,774
Tunis.....	2,050,200 tons, valued at	7,500,000
Christmas Island..	159,459 tons, valued at	2,024,036
France..... ...	313,151 tons, valued at	1,169,400
Algeria.....	207,111 tons, valued at	759,455
Belgium.....	203,110 tons, valued at	316,703
Other countries....	65,000 tons, valued at	280,000

For the United States production of 1912 the statistics are:

Florida.....	2,407,000 tons, valued at	$9,461,000
Tennessee.....	423,300 tons, valued at	1,640,500
South Carolina....	131,500 tons, valued at	524,700
Other States.....	11,600 tons, valued at	49,200

The total production was 3,020,905 tons, valued at $11,675,774.00, of which 1,206,520 tons, valued at $8,996,456.00 were exported. Partially offsetting this, there were imported guano, apatite and other phosphates to the value of about $2,000 000.

Pyromorphite ($Pb_4(PbCl)(PO_4)_3$)

In composition pyromorphite is PbO, 82.2 per cent, P_2O_5, 15.7 per cent and Cl, 2.6 per cent, but there are usually present also CaO and As_2O_5.

The mineral is completely isomorphous with apatite. Its crystals are smaller and simpler than those of apatite, but they have the same habit. Their axial ratio is $a : c = 1 : .7293$. This increases to $1 : .7354$ in varieties containing calcium.

Crystals are often rounded into barrel-shaped forms, and frequently are mere skeletons. Tapering groups of slender crystals in parallel growths are also common. Their cleavage is parallel to the $\infty P(110)$ faces, and their fracture is feebly conchoidal. The mineral also occurs in globular, granular and fibrous masses.

Pyromorphite is translucent. It is brittle, has a hardness of 3.5–4 and a density of about 7. Its luster is resinous and color usually green, yellow, brown or orange. Some varieties are gray or milk-white. Its streak is white. Its refractive indices for yellow light are: $\omega = 2.0614$, $\epsilon = 2.0494$. The mineral is distinctly thermo-electric.

When heated in the closed tube pyromorphite gives a white sublimate of lead chloride. It fuses easily, coloring the flame bluish green. When heated on charcoal it melts to a globule, which crystallizes on cooling and yields a coating which is yellow (PbO) near the assay and white ($PbCl_2$), at a greater distance from it. When fused with Na_2CO_3 on charcoal a globule of lead results. The mineral also gives the Cl and P reactions. The mineral is soluble in HNO_3.

Pyromorphite is recognized by its form, high specific gravity and its action when heated on charcoal.

Synthesis.—Crystals have been obtained by fusing sodium phosphate with $PbCl_2$.

Occurrence.—The mineral occurs principally in veins with other lead ores, especially in the zone of weathering. It also exists in pseudomorphs after galena.

Localities.—It is found in all lead-producing regions, especially in the upper portions of veins. It occurs in particularly good specimens at Příbram, Bohemia; at Ems, in Nassau; in Cornwall, Devon, Derby-

shire and Cumberland, England; at Phoenixville, Pennsylvania, and at various other points in the Appalachian region.

Uses.—Pyromorphite alone possesses no commercial value, but it is mined with other compounds of lead as an ore of this metal.

Mimetite ($Pb_4(PbCl)(AsO_4)_3$)

Mimetite, or mimetesite, resembles pyromorphite in its crystals and general appearance, and many of its properties. Its color, however, is lighter and its density slightly greater. It occurs in crystals, in filaments, and in concretionary masses and crusts. Its axial ratio is 1 : .7315 and its refractive indices for yellow light are: $\omega = 2.1443$, $\epsilon = 2.1286$.

The formula for mimetite demands 74.9 per cent PbO, 23.2 per cent As_2O_5 and 2.4 Cl. Usually a portion of the lead is replaced by CaO and a portion of the As by P.

Mimetite fuses more easily than pyromorphite. It differs from this mineral in yielding arsenical fumes when heated on charcoal. Moreover, when heated in a closed tube with a fragment of charcoal it coats the walls of the tube with metallic arsenic.

Occurrence and Localities.—It occurs with other lead minerals in veins, usually coating them either as crusts or as a series of small crystals. It is found at Phoenixville, Pennsylvania; in Cornwall, England; at Johanngeorgenstadt, in Germany; at Nerchinsk, Siberia; at Langban, in Sweden, and at a number of other places. It is, however, not as common as the corresponding phosphorus compound.

Uses.—It is mined with other compounds as an ore of lead.

Vanadinite ($Pb_4(PbCl)(VO_4))_3$

Vanadinite is the most widely distributed of all the vanadium minerals. It usually occurs in small bright red prismatic crystals implanted on other minerals, or on the walls of crevices in rocks. It is one of the sources of vanadium.

Its theoretical composition is as follows: PbO = 78.7 per cent, V_2O_5 = 19.4 per cent and Cl = 2.5 per cent, but phosphorus and arsenic are often also present. When arsenic and vanadium are present in nearly equal quantities the mineral is known as *endlichite*.

Its crystals are hexagonal prisms and pyramids bounded by $\infty P(10\bar{1}0)$, $oP(0001)$, $\infty P2(11\bar{2}0)$, $P(10\bar{1}1)$ and other forms, with an axial ratio 1 : .7122 (Fig. 154). Often the crystals have hollow faces

(Fig. 155). Frequently they are grouped into pyramids like those of pyromorphite. The mineral occurs also in globules and crusts.

Vanadinite is brittle, has a hardness of about 3 and a specific gravity of about 7. Its fracture is conchoidal. Its luster is adamantine or resinous and its color ruby red, brownish yellow or reddish brown. Its streak is white or light yellow. The mineral is translucent or opaque. Its refractive indices for yellow light are: $\omega = 2.354$, $\epsilon = 2.299$.

In the closed tube vanadinite decrepitates. It fuses easily on charcoal to a black lustrous mass which is reduced on being further heated in the reducing flame to a globule of lead. A white sublimate of $PbCl_2$ also coats the charcoal. The mineral, moreover, gives the flame test

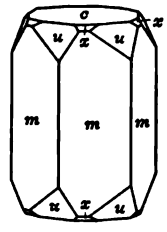


FIG. 154.

FIG. 155.

FIG. 154.—Vanadinite Crystal with ∞P, $10\bar{1}0$ (m); $0P$, 0001 (c); P, $10\bar{1}1$ (x), and $+\left[\frac{3P\frac{3}{2}}{2}\right]$, $21\bar{3}1$ (u).

FIG. 155.—Skeleton Crystal of Vanadinite.

for chlorine with copper. After complete oxidation of the lead by heating in the oxidizing flame on charcoal the residue gives an emerald-green bead in the reducing flame with microcosmic salt and this turns to a light yellow in the oxidizing flame. The mineral is soluble in hydrochloric acid. If to the solution a little hydrogen peroxide is added it will turn brown. The addition of metallic tin to this will cause it to turn blue, green and lavender in succession, in consequence of the reduction of the vanadium compounds.

Vanadinite is easily distinguished from most other minerals by its color. It is distinguished from other compounds of the same color by its crystallization and by the reactions for vanadium.

Occurrence.—Vanadinite occurs principally in regions of volcanic rocks. It is probably a result of pneumatolytic processes.

Localities.—Crystals are found at Zimapan, Mexico; Wanlockhead,

England; Undenäs, Sweden; in the Sierra de Córdoba, Argentine, and in the mining districts of Arizona and New Mexico.

Uses.—Vanadinite is an important source of vanadium, which is employed in the manufacture of certain grades of steel and bronze. Its compounds are, moreover, used as pigments and mordants. Most of the vanadium compounds produced in this country are obtained from other vanadium minerals, among them *patronite*—a mixture, of which the principal component is a sulphide (VS_4)—and carnotite (p. 290), but vanadinite has been used abroad and also to a small extent in the United States.

WAGNERITE GROUP

This group, in chemical composition, is analogous to the apatite group. It includes a number of phosphates and arsenates containing a fluoride radical. The group is monoclinic (prismatic class), with an axial ratio which is approximately 1.9 : 1 : 1.5, with $\beta = 71° 50'$. None of its members are important. The two most common ones are *wagnerite* ($Mg(MgF)PO_4$), and *triplite* ($Fe \cdot Mn$) $((Fe \cdot Mn)F)PO_4$.

Wagnerite occurs in massive forms and in large rough crystals, with imperfect cleavages parallel to $\infty P \bar{\infty}$ (100) and ∞P(110). Its crystals have an axial ratio of 1.9145 : 1 : 1.5059 with $\beta = 71° 53'$. They are often very complex. The mineral is brittle. Its fracture is uneven. Its hardness is 5.5 and density 3.09. Its color is yellow, gray, pink or green. It is vitreous, translucent and has a white streak. Its refractive indices are: $\alpha = 1.569$, $\beta = 1.570$, $\gamma = 1.582$. It fuses to a greenish gray glass and gives the usual reactions for fluorine and phosphoric acid. It is soluble in HCl and HNO_3, and heated with H_2SO_4 it yields hydrofluoric acid. It occurs in good crystals near Werfen, Austria, and in coarse crystals near Bamle, Norway.

Triplite is an isomorphous mixture of $Fe(FeF)PO_4$ and $Mn(MnF)PO_4$. It usually occurs massive, but is found in a few places in rough crystals. The mineral is dark brown or nearly black, is translucent to opaque, and has a yellowish gray or brown streak. It possesses two unequal cleavages perpendicular to one another and a weakly conchoidal fracture. Its hardness is 4–5.5 and specific gravity about 3.9. Its luster is resinous. Its intermediate refractive index is 1.660.

Before the blowpipe triplite fuses easily (1.5) to a black magnetic globule. It reacts for Mn, Fe, F, and P_2O_5. It is soluble in HCl and evolves hydrofluoric acid with H_2SO_4. It is found in coarse granite

veins at Limoges, France; Helsingfors, Finland; Stoneham, Maine; and Branchville, Connecticut. In all of its occurrences it appears to be pneumatolytic.

BASIC PHOSPHATES AND ARSENATES

The basic phosphates are those in which there is more metal present than sufficient to replace the three hydrogen atoms in the normal acid, H_3PO_4. This is due to the replacement of one or more of the hydrogen atoms by a group of atoms consisting of a metal and hydroxyl (OH). All yield water when heated in the closed tube.

The principal basic phosphates are *amblygonite*, a source of lithium compounds, *dufrenite* and *lazulite*, neither of which is of economic importance, and *libethenite*, a copper compound which occurs in comparatively small quantities with other copper ores, and is mined with them.

Olivenite is a basic copper arsenate corresponding to the phosphate libethenite.

Amblygonite ($Li(Al(F \cdot OH))PO_4$)

Amblygonite is an isomorphous mixture of the two compounds $(AlF)LiPO_4$ and $(AlOH)LiPO_4$. It is an important source of lithium.

The composition of the fluorine molecule is $Al_2O_3 = 34.4$ per cent, $LiO_2 = 10.1$ per cent and $P_2O_5 = 47.9$ per cent, making a total of 105.3 per cent from which deducting 5.3 per cent ($O = 2F$), leaves 100. Nearly always a portion of the F is replaced by OH and a part of the Li by Na. The pure $Na(AlOH)PO_4$ is known as *fremontite*, and the pure $Li(AlOH)PO_4$ as *montebrasite*.

The analysis of a specimen from Pala, California, gave:

P_2O_5	Al_2O_3	Fe_2O_3	MnO	MgO	Li_2O	Na_2O	H_2O			O = F	Total
48.83	33.70	.12	.09	.31	9.88	.14	5.95	2.29	= 101.31	−.96	= 100.45

The mineral forms large, ill-defined triclinic crystals (Fig. 156), and compact masses with a columnar cleavage. Crystals are very rare, and are poorly developed. Their axial ratio is .7334 : 1 : .7633. The cleavage pieces often show polysynthetic twinning lamellae parallel to $'P'\bar{\infty}$ (101) and $_{,}P_{,}\bar{\infty}$ ($\bar{1}01$).

The cleavage of the mineral is perfect parallel to oP(001). Its fracture is uneven. It is brittle, has a hardness of 6 and a density of 3.03. Its color is white, gray, or a very light tint of blue, pink or yellow. Its luster is vitreous, except on oP where it is pearly. Its

streak is white and it is translucent. Its refractive indices for yellow light are: $\alpha = 1.579$, $\beta = 1.593$, $\gamma = 1.597$.

In the closed tube at high temperature it yields water which reacts acid and corrodes glass. It fuses easily to an opaque white enamel. It colors the flame red with a slight fringe of green. When moistened with H_2SO_4 it tinges the flame bluish green. When finely powdered it dissolves readily in H_2SO_4 and with difficulty in HCl.

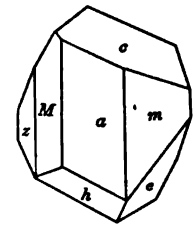


FIG. 156.—Amblygonite Crystal with $\infty P\bar{\infty}$, 100 (*a*); oP, 001 (*c*); $\infty'P$, $1\bar{1}0$ (*M*); $\infty P'$, 110 (*m*); $\infty'P\breve{2}$, $1\bar{2}0$ (*z*); $'P\bar{\infty}$, $\bar{1}01$ (*h*) and $2'P\breve{\infty}$, $0\bar{2}1$ (*e*).

Amblygonite resembles in appearance many other minerals, especially spodumene (p. 378), and some forms of barite, feldspar, dolomite, etc. From *spodumene* it is distinguished by the phosphorus reaction and the acid water; from the others by its easy fusibility.

Occurrence.—Amblygonite is found in granite and in pegmatite veins associated with other lithium compounds, tourmaline, cassiterite and other minerals of pneumatolytic origin. In all cases it also is probably a result of pneumatolytic action associated with the last phases of granite intrusions.

Localities.—The mineral occurs near Penig, in Saxony; at Arendal, in Norway; at Montebras, France; at Hebron, Paris and Peru, Maine; at Branchville, Conn.; at Pala, in California; and near Keystone, in the Black Hills, South Dakota.

Uses and Production.—The mineral is the principal source of lithium compounds in the United States. It is used in the manufacture of $LiCO_3$, which is employed as a medicine, in making mineral waters, in photography and in pyrotechnics.

It has been mined in South Dakota and in California to the extent of a couple of thousand tons, valued perhaps at $20,000.

Dufrenite ($Fe_2(OH)_3PO_4$)

Dufrenite, or kraurite, is a basic iron phosphate containing 62 per cent Fe_2O_3, 27.5 per cent P_2O_5 and 10.5 per cent water. It may be regarded as a normal phosphate in which one H atom of H_3PO_4 has been replaced by the $Fe(OH)_2$ group and two by the group Fe(OH), thus

$$HO—Fe{=}PO_4—Fe\begin{cases}OH.\\OH\end{cases}$$

It forms small orthorhombic crystals with a cubic habit that are rare. Their axial ratio is .3734 : 1 : .4262. It usually occurs massive, in

nodules, or in fibrous radiating aggregates. The same substance is believed to occur also in the colloidal condition under the name *delvauxite*.

The color of dufrenite varies from leek-green to dark green, which alters on exposure to yellow and brown. It is translucent to opaque, has a light green streak and is strongly pleochroic. Its hardness is 3.5–4 and specific gravity about 3.3.

In the closed tube it yields water and whitens. It fuses easily, coloring the flame bluish green and yielding a magnetic globule. It is soluble in HCl and in dilute H_2SO_4.

It is recognized by its color and the presence in it of water, phosphorus and iron.

Localities and Origin.—The mineral has been observed at several points in Europe; at Allentown, New Jersey, and in Rockbridge County, Virginia. It is thought to be produced by the weathering of other ferruginous phosphates.

Lazulite $((Mg \cdot Fe)(AlOH)_2(PO_4)_2)$

Lazulite is essentially an isomorphous mixture of the two compounds $Mg(AlOH)_2(PO_4)_2$ and $Fe(AlOH)_2(PO_4)_2$. There is also frequently present in it a little calcium. When the proportion of the two molecules present is as 2 : 1 the composition becomes FeO = 7.7; MgO = 8.5; Al_2O_3 = 32.6; P_2O_5 = 45.4 and H_2O = 5.8.

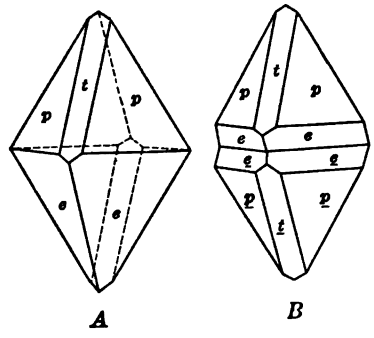


FIG. 157.—Lazulite Crystals. A with −P, 111 (*p*); +P, 11$\bar{1}$ (*e*) and P$\bar{\infty}$, 101 (*t*). B is the same combination twinned about ∞P$\bar{\infty}$ (100), with oP (001) the composition face.

The mineral occurs in blue pyramidal crystals that are monoclinic (prismatic class), with the axial ratio = .9750 : 1 : 1.6483 and $\beta = 89° 14'$. The predominant forms are +P(11$\bar{1}$), −P(111) and −P$\bar{\infty}$ (101)(Fig. 157*A*). The angle 111 ∧ 1$\bar{1}$1 = 79° 40′. Twins are not common. Those most frequently found are twinned about *c* as the twinning axis (Fig. 157B). It is found also massive and in granular aggregates.

The cleavage of lazulite is not distinct. Its fracture is uneven. It is brittle, has a vitreous luster, is translucent or opaque, has an azure color and a white streak. Its hardness is 5 or 6 and its specific gravity about 3.1. Translucent crystals are strongly pleochroic in deep blue and greenish blue tints—the former when viewed along the vertical

axis. Their indices of refraction for yellow light are: $\alpha = 1.603$, $\beta = 1.632$, $\gamma = 1.639$.

In the closed tube lazulite swells, whitens and yields water. When heated in the blowpipe flame it whitens, falls to pieces and colors the flame bluish green. The white powder moistened with $Co(NO_3)_2$ and reheated regains its blue color. When moistened with H_2SO_4 and heated in the blowpipe flame it imparts to it a green blue color. It is infusible and is unacted upon by acids.

Lazulite, when massive, closely resembles in appearance massive forms of some varieties of *sodalite*, *haüynite* and *lazurite* (p. 333). The latter, however, are soluble in HCl. Moreover, none of them contains phosphorus.

Occurrence.—The mineral occurs in quartz veins in sandstones and slates and is usually a product of metamorphism. It is sometimes, however, found in serpentine rocks, with corundum, in which case it may be original.

Localities.—Good crystals occur at Krieglach, in Styria; at Horrsjöberg, in Sweden, and in the United States at Crowder's Mountain, North Carolina, and on Graves Mountain in Georgia.

OLIVENITE GROUP

The olivenite group includes a number of basic copper, lead and zinc compounds of the general formula $R''_2(OH)R'''O_4$ in which $R'' = Cu, Zn, Pb$ and $R''' = As, P, V$. The group is orthorhombic (bipyramidal class), with axial ratios approximating .95 : 1 : .70. The most important members of the group are the two copper minerals, *olivenite*, $Cu(CuOH)AsO_4$ and *libethenite*, $Cu(CuOH)PO_4$.

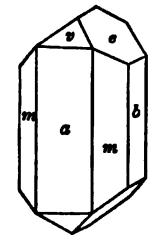


FIG. 158.—Olivenite Crystal with $\infty P\bar{\infty}$, 100 (*a*); ∞P, 110 (*m*); $\infty P\breve{\infty}$, 010 (*b*); $P\breve{\infty}$, 011 (*e*) and $P\bar{\infty}$, 101 (*v*).

Olivenite occurs in fibrous, globular, lamellar, granular and earthy masses and in prismatic and acicular crystals bounded by $\infty P(110)$, $\infty P\bar{\infty}(100)$, $\infty P\breve{\infty}(010)$, $P\breve{\infty}(011)$ and $P\bar{\infty}(101)$ (Fig. 158). Their axial ratio is .9396 : 1 : .6726 and the angle $110 \wedge 1\bar{1}0 = 86° 26'$. Their cleavage is poor.

The mineral is some shade of green, brown, yellow or grayish white and its streak is olive-green in greenish varieties. It is transparent to opaque, is brittle, has a hardness = 3, and a specific gravity = 4.3. Its refractive indices for

yellow light are about 1.83. Its luster is usually vitreous. Fibrous varieties are sometimes known as wood-copper.

Olivenite fuses easily (2) to a mass that appears crystalline on cooling. It gives the usual reactions for H_2O, Cu, and As. It is soluble in acids and in ammonia.

It is associated with other copper compounds in some copper ores. Its origin is secondary in all cases. It occurs in the Tintic district, Utah, and in many copper veins in Europe and in South America.

Libethenite occurs in compact or globular masses and in small crystals that resemble those of olivenite. Their axial ratio is .9605 : 1 : .7019 and $110 \wedge 1\bar{1}0 = 87° 40'$.

The mineral is brittle. Its fracture is indistinctly conchoidal. Its color is dark olive-green and its streak a lighter shade. It is translucent or transparent and has a resinous luster. Its hardness = 4 and sp. gr. = 3.7. Its intermediate refractive index for yellow light is 1.743.

When heated in the closed tube it yields water and blackens. It is easily fusible (2). It yields the usual reaction for Cu and P, and is soluble in acids and in ammonia. It is distinguished from *olivenite* by the reaction for phosphorus.

It occurs at many of the localities for olivenite, where, like this mineral, it is a decomposition product of other copper compounds.

Herderite ($CaBe(OH \cdot F)PO_4$)

Herderite is an isomorphous mixture of the two phosphates, $CaBeFPO_4$ and $CaBe(OH)PO_4$. The latter molecule occurs in nature as *hydroherderite*; the former occurs only in mixtures. The theoretical composition of the fluorine (I) and hydroxyl (II) molecules and of transparent crystals from Stoneham (III), and Paris (IV), Maine, are given below:

	BeO	CuO	P_2O_5	F	H_2O	Ins.	Total (less O = F)
I.	15.39	34.33	43.53	11.64	....	...	100
II.	15.53	34.78	44.10	....	5.59	...	100
III.	15.51	33.67	43.74	5.27	3.70	...	99.67
IV.	16.13	34.04	44.05	5.85	....	.44	100.51

The mineral is found only in crystals, which are monoclinic, with $a : b : c = .6301 : 1 : .4274$ and $\beta = 89° 54'$. Their habit is hexagonal, pyramidal or short prismatic, elongated in the direction of a.

Herderite is colorless or light yellow, transparent or translucent. Its refractive indices are: $\alpha = 1.592$, $\beta = 1.612$, $\gamma = 1.621$.

Its density is about 3, diminishing, as the amount of hydroxyl increases, to 2.952 in the pure hydroherderite.

Before the blowpipe herderite first phosphoresces with an orange-yellow light, then fuses to a white enamel, colors the flame red and yields fluorine. In the closed glass tube most specimens yield an acid water, which, when strongly heated, evolves fluorine that etches the glass. The mineral also reacts for phosphorus with magnesium ribbon. It is slowly soluble in HCl.

Occurrence, Origin and Uses.—Herderite occurs in pegmatite dikes at Stoneham, Hebron, and other places in Maine, and at the tin mines of Ehrenfriedersdorf, Saxony; in all of these places it is apparently of pneumatolytic origin. The material from Maine is used to a small extent as a gem stone.

ACID PHOSPHATES

Acid phosphates are those in which all of the hydrogen atoms of the acids have not been replaced by metals or by basic radicals. Theoretically, they contain replaceable hydrogen atoms. There are 12 or 15 minerals that are thought to belong to this class, but the composition of many of them is very obscure. Most of them appear to be hydrated. The only important mineral that may belong to the class is the popular gem stone, *turquoise.* This, according to the best analyses, contains its components in the proportions indicated by the formula CuO, $3Al_2O_3$, $2P_2O_5$, $9H_2O$, which may be interpreted as $(CuOH)(Al(OH)_2)_6H_5(PO_4)_4$. which is $4(H_3PO_4)$, in which 6 hydrogen atoms are replaced by $6Al(OH)_2$ groups and one by the group CuOH.

Turquoise ($(CuOH)(Al(OH)_2)_6H_5(PO_4)_4$)

Turquoise is apparently a definite compound of the formula indicated above, which requires 34.12 per cent P_2O_5, 36.84 per cent Al_2O_3, 9.57 per cent CuO and 19.47 per cent H_2O. Analysis of a crystallized variety from Lynch, Campbell Co., Virginia, gave:

P_2O_5	Al_2O_3	Fe_2O_3	CuO	H_2O	Total
34.13	36.50	.21	9.00	20.12	99.96

Most specimens, however, have not as simple a composition as this. They are probably isomorphous mixtures of unidentified phosphates.

The mineral as usually found is apparently an amorphous or cryptocrystalline, translucent or opaque material with a waxy luster and a sky-blue, green or greenish gray color. Material recently found at Lynch, Virginia, however, occurs in minute triclinic crystals with an axial ratio .7910 : 1 : .6051, with $\alpha = 87° 02'$, $\beta = 86° 29'$, and $\gamma = 72° 19'$. Their habit is pyramidal with $\infty P \bar{\infty}$ (100), $\infty P \breve{\infty}$ (010), $\infty P'(1\bar{1}0)$, $\infty P'(110)$ and $P \bar{\infty}$ $(0\bar{1}1)$.

The fracture of turquoise is conchoidal. It has a hardness of 5-6 and a specific gravity between 2.61 and 2.89. It is brittle, and has cleavages in two directions. The determined refractive indices of the Virginia crystals are: $\alpha = 1.61$, $\gamma = 1.65$.

In the closed tube the mineral decrepitates, yields water and turns black or brown. It is infusible, but it assumes a glassy appearance when heated before the blowpipe and colors the flame green. When moistened with HCl and again heated the flame is tinged with the azure blue of copper chloride. The mineral reacts for copper and phosphoric acid. Some specimens dissolve in HCl, but the crystallized material from Virginia is insoluble until after it is strongly ignited. It partly dissolves in KOH, with the production of a brown residue of a copper compound.

Occurrence.—Turquoise occurs in thin veins cutting through certain decomposed volcanic rocks and other rocks in contact with them, and in grains disseminated through them, in stalactites, globular masses and crusts. It is probably an alteration product of other compounds.

Localities.—Turquoise is found in narrow veins and irregular masses in the brecciated portions of acid volcanic rocks and the surrounding clay slates, near Nishâpur, in Persia; in the Megara Valley, Sinai, and near Samarkand, in Turkestan. In all these places the mineral is of gem quality and until recently nearly all the gem turquoise came from them. Within late years gem turquoise has been discovered in the Cerillo Mountains, near Santa Fé, New Mexico, where it has been mined in considerable quantity. The locality is the site of an ancient mine which was worked by the Mexicans. It is also found and mined in the Burro Mountains, Grant County, in the same State, near Millers, and at other points in Nevada and near Mineral Park, Mohave County, Arizona, where also the ancient Mexicans once had mines. At La Jara, Conejos County, Colorado, old mines have likewise been opened up and are now yielding gem material.

Uses.—The only use of turquoise is as a gem stone. Though much of the American mineral is pale or green, some of it is of as fine color as the Oriental stone. A favorite method of using the stone is in its

matrix. Small pieces of the rock with its included turquoise are polished and sold under the name of turquoise matrix.

Production.—The total value of the turquoise and turquoise matrix produced in the United States during 1911 was $44,751. This weighed about 4,363 pounds. In several previous years the production reached about $150,000, but in 1912 it was valued at only $10,140.

HYDROUS PHOSPHATES AND ARSENATES

HYDRATED NORMAL PHOSPHATES AND ARSENATES

Of the hydrous salts of orthophosphoric and orthoarsenic acids there are two which are of some importance because they are fairly common, a third which is utilized in jewelry, and a fourth that is important as an indicator of the presence of an ore of cobalt. The first two are *vivianite* and *scorodite*, a phosphate and an arsenate of iron, the third is *variscite*, an aluminium phosphate, and the fourth is *erythrite*, an arsenate of cobalt. A dimorph of variscite, known as *lucinite*, is rare. All give water in the closed tube and yield phosphine when fused with magnesium and moistened with water.

VIVIANITE GROUP

The only important group of the hydrated orthophosphates and orthoarsenates is that of which vivianite and erythrite are members. The general formula of the group is $R''_3(R'''O_4)_2 \cdot 8H_2O$ in which R'' = Fe, Co, Ni, Zn and Mg, and $R''' = P$ or As. Although some members have not been found in measurable crystals, crystals of all have been made in the laboratory, so that there is little doubt of their isomorphism. All are monoclinic prismatic with axial ratios of about .75 : 1 : .70 and β about 74°. The group is as follows:

Bobierite, $Mg_3(PO_4)_2 \cdot 8H_2O$	*Erythrite*, $Co_3(AsO_4)_2 \cdot 8H_2O$
Hörnesite, $Mg_3(AsO_4)_2 \cdot 8H_2O$	*Annabergite*, $Ni_3(AsO_4)_2 \cdot 8H_2O$
Vivianite, $Fe_3(PO_4)_2 \cdot 8H_2O$	*Cabrerite*, $(Ni \cdot Mg)_3(AsO_4)_2 \cdot 8H_2O$
Symplesite, $Fe_3(AsO_4)_2 \cdot 8H_2O$	*Köttigite*, $Zn_3(AsO_4)_2 \cdot 8H_2O$

Only vivianite, erythrite and annabergite are described.

Vivianite ($Fe_3(PO_4)_2 \cdot 8H_2O$)

Vivianite is a common phosphate of iron. It occurs not only in distinct crystals but also as bluish green stains on other minerals, and as an invisible constituent of certain iron ores, thereby diminishing their value.

Its formula indicates the presence of 43 per cent FeO, 28.3 per cent P_2O_5 and 28.7 per cent H_2O.

Vivianite crystals are monoclinic (prismatic class), usually with a prismatic habit. Their axial ratio is .7498 : 1 : .7015, and $\beta = 75° 34'$. The principal forms observed on them are $\infty P \bar{\infty}$ (100), $\infty P \breve{\infty}$ (010), ∞P(110), $\infty P\bar{3}$(310), $P \bar{\infty}$ (101), P(111) and oP(001). The angle $110 \wedge 1\bar{1}0 = 71° 58'$. The mineral also occurs in stellate groups, in globular, fibrous and earthy masses and as crusts coating other compounds.

Its cleavage is perfect parallel to $\infty P \breve{\infty}$ (010). It is flexible in thin splinters and sectile. The fresh, pure mineral is colorless and transparent, but specimens usually seen are more or less oxidized and have a blue or green color. It has a vitreous to pearly luster. Its streak is white or bluish, changing to indigo-blue or brown on exposure to the air. Its pleochroism is strong in blue and pale yellow tints. Its hardness is 1.5–2 and density about 2.6. Its refractive indices for yellow light are: $\alpha = 1.5818$, $\beta = 1.6012$, $\gamma = 1.6360$.

In the closed tube vivianite whitens, exfoliates and yields water at a low temperature. It fuses easily (2), tingeing the flame bluish green. Its fusion temperature is 1114°. The fused mass forms a grayish black magnetic globule. It gives the reaction for iron, and is soluble in HCl.

The mineral is easily recognized by its softness, easy fusibility and by yielding the test for phosphorus.

Synthesis.—Crystals have been made by heating iron phosphate with a great excess of sodium phosphate for eight days.

Occurrence and Origin.—Vivianite occurs in veins of copper, tin and gold ores; disseminated through peat, clay, and limonite; coating the walls of clefts in feldspars and other minerals of certain igneous rocks, and partially filling cavities in fossils and partly fossilized bones. It is usually the result of the decomposition of other minerals.

Localities.—Crystals are found at several points in Cornwall, England; at the gold mines at Verespatak, in Transylvania; at Allentown, Monmouth County, New Jersey, and at many other places. The earthy variety occurs at Allentown, Mullica Hill and other points in New Jersey, in Stafford County, Virginia, and in swamp deposits at many places. It is abundant in limonite at Vaudreuil, in Quebec, and in bog iron ores elsewhere.

Erythrite ($Co_3(AsO_4)_2 \cdot 8H_2O$)

Erythrite, or cobalt bloom, is not a common mineral, but, because of its beauty and the fact that it is the usual alteration product of cobalt ores, it deserves to be described.

In composition erythrite is 37.5 per cent CoO, 38.4 per cent As_2O_5, and 24.1 per cent H_2O. It usually, however, contains some iron, nickel and calcium.

The mineral is isomorphous with vivianite. Its crystals are monoclinic and prismatic or acicular and their axial ratio is .7937 : 1 : .7356 and $\beta = 74° 51'$. The prisms are striated vertically. Erythrite occurs in all the forms in which vivianite is found. Its crystals are usually bounded by $\infty P \breve{\infty}$ (010), ∞P(110), $\infty P \bar{\infty}$ (100), $+P \bar{\infty}$ ($\bar{1}01$) and P($\bar{1}11$).

The cleavage of erythrite is perfect parallel to $\infty P \breve{\infty}$ (010). It is transparent or translucent, has a gray, crimson or peach-red color, and a white or pink streak. Its hardness varies between 1.5 and 2.5 and its density is 2.95. Its luster is pearly on $\infty P \breve{\infty}$ (010) and vitreous on other faces. It is flexible and sectile. Its refractive indices for yellow light are: $\alpha = 1.6263$, $\beta = 1.6614$, $\gamma = 1.6986$.

In the closed tube erythrite turns blue and yields water at a low temperature. At a high temperature it yields As_2O_3, which condenses in the cold portion of the tube as a dark sublimate. It fuses at 2, and tinges the flame pale blue. On charcoal it fuses, yields arsenic fumes and a gray globule which colors the borax bead a deep blue. The mineral is soluble in HCl, giving rise to a pink solution, which, upon evaporation to dryness, gives a blue stain.

It is easily recognized by its color and the cobalt reaction. It is readily distinguished from pink *tourmaline* (p. 434), by its hardness and easy fusibility.

Synthesis.—Crystals have been obtained by carefully mixing together warm solutions of $CoSO_4$ and $HNa_2AsO_4 \cdot 7H_2O$.

Occurrence.—Erythrite occurs in the upper portions of veins containing cobalt minerals, being formed by their weathering.

Localities.—It occurs as scales and crystals at Schneeberg, Saxony, and as crystals at Modum, Norway. It is found, also, at Lovelock's Station, Nevada, at several points in California and in large quantities at Cobalt, Ontario.

Annabergite ($Ni_3(AsO_4)_2 \cdot 8H_2O$)

Annabergite, or nickel bloom, is isomorphous with erythrite. It occurs massive, disseminated in tiny grains through certain rocks, as crusts and stains in globular and earthy masses, and in fibrous crystals, the axial ratios of which are not known.

The mineral is apple-green in color, and is translucent or opaque.

Its streak is light green. Its luster is vitreous; its hardness, 1.5–2.5 and sp. gr. = 3.

Before the blowpipe it melts to a gray globule and gives the arsenic odor. In the closed glass tube it blackens and yields water. In the beads it gives the usual reactions for Ni. The mineral dissolves easily in acids.

Synthesis.—Crystals have been produced by the method employed in the synthesis of erythrite, using $NiSO_4$, instead of $CoSO_4$.

Occurrence.—It is found as a common alteration product of nickel-bearing minerals, in the oxidized portions of veins.

Localities.—Its best known occurrences are in Allemont, Dauphiné; Annaberg and Schneeberg, Saxony; Cobalt, Ontario, and mines in Colorado and Nevada.

Variscite ($AlPO_4 \cdot 2H_2O$)

Variscite is a bright green mineral that has recently come into use as a gem material. It is apparently an aluminium phosphate with a theoretical composition as follows: 44.9 per cent P_2O_5; 32.3 per cent Al_2O_3 and 22.8 per cent H_2O. A specimen of crystallized material from Lucin, Utah, gave the following analysis:

P_2O_5	Al_2O_3	Fe_2O_3	CrO_3	V_2O_3	H_2O	Total
44.73	32.40	.06	.18	.32	22.68	100.37

Recent investigations indicate that the compound $AlPO_4 \cdot 2H_2O$ is dimorphous. Both forms are orthorhombic but one, variscite, has the properties described under this heading. The other, *lucinite*, is associated with variscite, near Lucin, Utah. It, however, occurs in crystals that are octahedral in habit, rather than tabular, and that have an axial ratio of .8729 : 1 : .9788. In other respects lucinite is very much like variscite.

An amorphous variety of the same substance is also known. It occurs as a white, pale brown or pale blue earthy mass with a sp. gr. of 2.135. It differs from the crystalline varieties in being completely soluble in warm concentrated H_2SO_4.

The crystals of variscite are orthorhombic and are bounded by $\infty P \breve{\infty}$ (010), ∞P(110) and $\frac{1}{2}P \breve{\infty}$ (012), and in a few cases $\infty P \bar{\infty}$ (100). Their axial ratio is .8944 : 1 : 1.0919. Nearly all crystals are tabular parallel to $\infty P \breve{\infty}$ (010). Twins are common, with $\frac{1}{2}P \bar{\infty}$ (102) the twinning plane. Crystals are comparatively rare, the mineral occurring usually in fibrous or finely granular masses and as incrustations.

Variscite varies in color from a pale to a bright green. It is weakly pleochroic, has a vitreous luster, a hardness of about 4 and a density of 2.54. Its refractive indices for yellow light are: $\alpha=1.546$, $\beta=1.556$, $\gamma=1.578$.

Before the blowpipe the mineral is infusible. It, however, whitens and colors the flame deep bluish green. It yields water in the closed tube, and with the loss of its water, it changes color from green to lavender. The same change in color takes place gradually at temperatures between 110°–160°. When heated with $Co(NO_3)_2$, it turns blue and when fused with magnesium ribbon it gives the test for phosphorus. It forms a yellowish green glass with borax or microcosmic salt. The mineral is insoluble in acids before heating.

Variscite resembles in some respects certain varieties of *turquoise* and *wavellite* (p. 287). It is distinguished from turquoise by the absence of copper and from wavellite by its insolubility in acids.

Occurrence.—The mineral occurs as a cement in a brecciated, cherty limestone and a brecciated rhyolite, as nodules in the cherty portions of the breccias and also as veins traversing these rocks. It is also found as nests in weathered pegmatites. The crystals occur as coarsely granular, loosely coherent masses in more compact granular masses.

Localities.—Variscite occurs at Messbach, Saxony; in Montgomery County, Arkansas; near Lucin, Utah, and at a number of other places in Tooele and Washington Counties in this State; in Esmeralda County, Nevada, and in Montgomery County, Arkansas. The colloidal variety occurs as concretions in slates at Brandberg, near Leoben, Austria.

Uses.—The mixture of variscite and rock is cut, and employed as sets in necklaces, belt pins, etc., under the names "utahlite" and "amatrice," but because of the softness of the variscite it cannot be used with success for all the purposes for which turquoise matrix is used.

Production.—The production of the material in the United States during 1911 was 540 lb., valued at $5,750. In the previous year 5,377 lb. were reported as having been sold for $26,125. In 1912, the amount marketed was valued at $8,150.

Skorodite ($FeAsO_4 \cdot 2H_2O$)

Skorodite is more common than vivianite. It occurs in globular and earthy masses, as incrustations, and in crystals of a green or brown color. The globular forms are colloidal.

Its formula indicates $Fe_2O_3=34.6$ per cent, $As_2O_3=49.8$ per cent

and $H_2O = 15.6$ per cent. An incrustation on the deposits of the Joseph's Coat Spring, Yellowstone National Park, consisted of:

As_2O_5	Fe_2O_3	H_2O	SiO_2	SO_3	Total
46.48	33.29	15.50	4.35	.84	100.46

Its crystallization is orthorhombic (bipyramidal class), with $a : b : c = .8658 : 1 : .9541$. The crystals, which are commonly bounded by $\infty P\bar{\infty}$ (100), $\infty P\breve{\infty}$ (010), $\infty P\breve{2}$(120), ∞P(110), P(111) and $\frac{1}{2}$P(112), are either prismatic or octahedral in habit (Fig. 159). The angle $111 \wedge 1\bar{1}1 = 65° 20'$. Their cleavage is imperfect, parallel to ∞P(110).

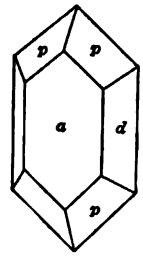


FIG. 159. — Skorodite Crystal with $\infty P\bar{\infty}$, 100 (*a*); $\infty P\breve{2}$, 120 (*d*), and P, 111 (*p*).

The mineral is brittle. It has a vitreous luster, a leek-green or liver-brown color and a white streak. It is translucent and has an uneven fracture. Its hardness is 3.5–4 and density about 3.3. The colloidal phases are somewhat softer than the crystalline phases.

In the closed tube skorodite turns yellow and yields water. It fuses easily, coloring the flame bluish. On charcoal it yields white arsenical fumes and gives a black porous, magnetic button. It is soluble in HCl, forming a brown solution.

It is distinguished from *vivianite* by the arsenic test, and from *dufrenite* by its streak and reaction in the closed tube.

Synthesis.—Skorodite crystals have been made by heating metallic iron with concentrated arsenic acid solution at 140°–150°.

Occurrence.—Skorodite is frequently associated with arsenopyrite, in the oxidized portions of veins containing iron minerals. It is found also in a few places as incrustations deposited by hot springs.

Localities.—It occurs in fine crystals at Nerchinsk, Siberia; at Loelling, in Carinthia; near Edenville, New York; in the Tintic district, Utah, and as an incrustation on the siliceous sinter of the geysers in Yellowstone Park.

HYDRATED BASIC PHOSPHATES AND ARSENATES

The hydrated basic phosphates and arsenates are rather more numerous than the hydrated normal compounds, but most of them are rare. One, *wavellite*, however, is a handsome mineral that is fairly common. Another, *pharmacosiderite*, an iron arsenate, is known to occur at a number of places. The *uranite* group also belongs here. Its members

are comparatively rare, but, because of the presence of uranium in them, they are of considerable interest.

Wavellite ($(Al(OH \cdot F)_3)(PO_4)_2 \cdot 5H_2O$)

Wavellite rarely occurs in crystals. It is usually in acicular aggregates that are either globular or radiating (Fig. 160). The few crystals that have been seen are orthorhombic (bipyramidal class), with an axial ratio of .5573 : 1 : .4057.

Its composition varies widely, and frequently a fairly large portion of the OH is replaced by F, and a portion of the Al by Fe.

The mineral is vitreous in luster and white, green, yellow, brown or black in color. Its streak is white. It is brittle and translucent, in-

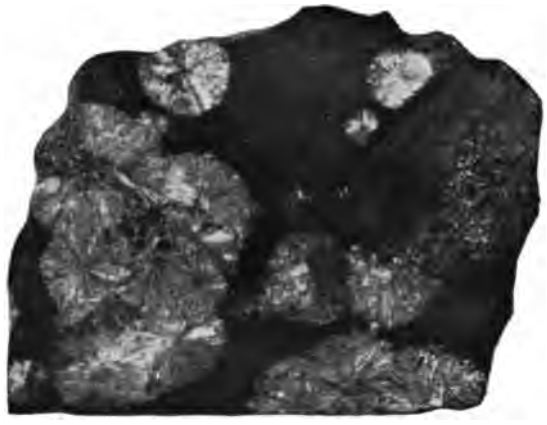


FIG. 160.—Radiate Wavellite on a Rock Surface.

fusible and insoluble in acids. Its hardness is 3.5 and its density 2.41. Its intermediate refractive index for yellow light is 1.526.

Heated in a closed glass tube, wavellite yields water, the last traces of which react acid and often etch the glass. In the blowpipe flame the mineral swells up and breaks into tiny infusible fragments, at the same time tingeing the flame green. The mineral is soluble in HCl and H_2SO_4. When heated with H_2SO_4 many specimens yield hydrofluoric acid. When heated on charcoal and moistened with $Co(NO_3)_2$ and reheated, the mineral turns blue.

Wavellite is distinguished from *turquoise*, which it sometimes resembles, by its action in the blowpipe flame, by its inferior hardness and its manner of occurrence.

Occurrence.—Wavellite occurs as radiating bundles on the walls of

cracks in various rocks and as globular masses filling ore veins and the spaces between the fragments of breccias. It is probably in all cases the result of weathering.

Localities.—It is found at a great number of places, especially at Zbirow, in Bohemia; at Minas Geraes, Brazil; at Magnet Cove, Arkansas, and in the slate quarries in York County, Penn.

Pharmacosiderite ($(FeOH)_3(AsO_4)_2 \cdot 5H_2O$)

Pharmacosiderite is a hydrated ferric arsenate, the composition of which is not firmly established. It usually occurs in small isometric crystals (hextetrahedral class), that are commonly combinations of $\infty O \infty$ (100) and $\frac{O}{2}$(111). It is also sometimes found in granular masses. Its cleavage is parallel to $\infty O \infty$ (100).

The mineral is green, dark brown or yellow. Its streak is a pale shade of the same color. It has an adamantine luster and is translucent. Its hardness $=2.5$ and sp. gr. $=3$. It is sectile and pyroelectric. Its refractive index, $n=1.676$.

Pharmacosiderite reacts like skorodite before the blowpipe and with reagents.

The mineral occurs in the oxidized portions of ore veins, in Cornwall, England; at Schneeberg, Saxony; near Schemnitz, Hungary; and in the Tintic district, Utah.

URANITE GROUP

The uranites are a group of phosphates, arsenates and vanadates containing uranium in the form of the radical uranyl (UO_2) which is bivalent. The members of the group are either tetragonal, or orthorhombic with a tetragonal habit. They all contain eight molecules of water of crystallization. Only three members of the group are of sufficient interest to be discussed here. These are the hydrated copper and calcium uranyl phosphates, *torbernite* and *autunite* and the potassium uranyl vanadate, *carnotite*.

The entire group so far as its members have been identified is as follows:

Autunite	$Ca(UO_2)_2(PO_4)_2 \cdot 8H_2O$	Orthorhombic
Uranospinite	$Ca(UO_2)_2(AsO_4)_2 \cdot 8H_2O$	Orthorhombic
Torbernite	$Cu(UO_2)_2(PO_4)_2 \cdot 8H_2O$	Tetragonal
Zeunerite	$Cu(UO_2)_2(AsO_4)_2 \cdot 8H_2O$	Tetragonal
Uranocircite	$Ba(UO_2)_2(PO_4)_2 \cdot 8H_2O$	Orthorhombic
Carnotite	$(Ca \cdot K_2)(UO_2)_2(VO_4)_2 \cdot xH_2O$	

The uranites are of interest because of their content of uranium, an element which is genetically related to radium.

Autunite ($Ca(UO_2)_2(PO_4)_2 \cdot 8H_2O$)

Autunite occurs in thin tabular crystals with a distinctly tetragonal habit, and in foliated and micaceous masses.

The percentage composition corresponding to the above formula is 6.1 per cent CaO, 62.7 per cent UO_3, 15.5 per cent P_2O_5 and 15.7 per cent H_2O.

Its crystals are orthorhombic (bipyramidal class), with an axial ratio, .9875 : 1 : 2.8517, thus possessing interfacial angles that closely approach those of torbernite. Its crystals are bounded by oP(001), P $\bar{\infty}$ (101), P $\breve{\infty}$ (011), and several less prominent planes. Their cleavage is very perfect and the cleavage lamellae are brittle. The luster is pearly on the base and vitreous on other surfaces.

The mineral is lemon-yellow or sulphur-yellow in color, and its streak is yellow. It is transparent to translucent. Its hardness is 2–2.5 and its specific gravity about 3.2. Its refractive indices for yellow light are: $\alpha = 1.553$, $\beta = 1.575$, $\gamma = 1.577$.

The mineral reacts like torbernite before the blowpipe and with acids, except that it shows none of the tests for copper. It is recognized by its color, streak and specific gravity.

Occurrence.—Autunite occurs in pegmatite veins and on the walls of cracks in rocks near igneous intrusions, especially in association with other uranium compounds, of which it is a decomposition product.

Localities.—It has been found at Johanngeorgenstadt, Germany; at Middletown and Branchville, Conn., in the mica mines of Mitchell County, North Carolina, and coating cracks in gneiss at Baltimore, Md.

Torbernite ($Cu(UO_2)_2(PO_4)_2 \cdot 8H_2O$)

Torbernite occurs in small square tables, that may be very thin or moderately thick, and in foliated and micaceous masses.

The pure mineral contains 61.2 per cent UO_3, 8.4 per cent Cu, 15.1 per cent P_2O_5 and 15.3 per cent H_2O, but frequently a part of the P is replaced by As.

Its crystals are tetragonal (ditetragonal bipyramidal class), with $a : c = 1 : 2.9361$. They are extremely simple, their predominating forms being oP(001) and P ∞ (101). Less prominent are ∞ P ∞ (100), 2P ∞ (201) and ∞ P(110). Their cleavage is perfect parallel to oP. The cleavage lamellae may be almost as thin as those of the micas but they are brittle.

The mineral is bright green in emerald, grass or apple shades, has a lighter green streak, is translucent or transparent, and has a hardness of 2.25 and a specific gravity of about 3.5. Its luster is pearly on the basal plane, but nearly vitreous on other surfaces. It is strongly pleochroic in green and blue.

Torbernite gives reactions for Cu and P and yields water in the closed tube. The bead reactions for uranium are masked by those of copper. The mineral is soluble in HNO_3.

The mineral is easily recognized by its color and other physical properties.

Occurrence.—Torbernite is occasionally found as a coating on the walls of crevices in rocks. It occurs in Cornwall, England; at Scheeberg, Saxony; at Joachimsthal, Bohemia, and at most places where other uranium minerals exist. It is probably in all cases a weathering product.

Carnotite $((Ca \cdot K_2)(UO_2)_2(VO_4)_2 \cdot xH_2O)$

Carnotite, like the other uranites described, is extremely complex in composition. It may be an impure potassium uranyl vanadate, or a mixture of several vanadates in which the potassium uranyl compound is the most prominent. The formula given above indicates its composition as well as any simple formula that has been proposed. A specimen from La Sal Creek, Colorado, shows the mineral to be essentially as follows:

V_2O_5	UO_3	CaO	BaO	K_2O	H_2O at 105°	H_2O above 105°
18.05	54.00	1.86	1.86	5.46	3.16	2.21

though there are present in the specimen analyzed, or in other specimens from the same locality, also As_2O_3, P_2O_5, SiO_2, TiO_2, CO_2, SO_3, MoO_3, Cr_2O_3, Fe_2O_3, Al_2O_3, PbO, CuO, SrO, MgO, Li_2O and Na_2O, and there are reported in them also small quantities of radium. Radiographs taken with the aid of carnotite have been published, which are almost as clear as those taken with pitchblende. The complete analysis of a specimen from the Copper Prince Claim, Montrose Co., Colo., gave:

V_2O_5	As_2O_5	P_2O_5	UO_3	MoO_3	Fe_2O_3	Al_2O_3	PbO
18.35	.25	.33	52.25	.23	1.77	1.08	.25
CuO	CaO	BaO	K_2O	H_2O-	H_2O+	Ins.	Total
.20	2.85	.72	6.73	2.59	3.06	8.34	99.84

Also TiO_2=.10; CO_2=33; SO_3=.12; CrO_3=tr.; MgO=.20 and Na_2O=.09.

The mineral has been found only in tiny crystalline grains, so that its physical properties are not well known. It is bright yellow in color, and is completely soluble in HNO_3. If to the nitric acid solution hydrogen peroxide be added a brown color will appear. Or if the solution is filtered, made alkaline by ammonia and through it is passed H_2S, a garnet color will develop. If the mineral be moistened by a drop of concentrated HCl, a rich brown color will result. The addition of a drop or two of water will change the color to light green or make it disappear.

Occurrence.—Carnotite occurs as a yellow crystalline powder, some of which seems to consist of minute crystals with an hexagonal habit, in the interstices between the grains in sandstones and conglomerates, as nodules or lumps in these rocks, and as coatings on the walls of cracks in pebbles in the conglomerates and on pieces of silicified wood embedded in the sandstones. It is limited to very shallow depths and is apparently a deposit from ground water.

Localities.—Its principal known occurrences are in Montrose, San Miguel, Mesa and Dolores Counties in southwestern Colorado, especially in Paradox Valley, and in adjoining portions of New Mexico and Utah, and in Rio Blanco and Routt Counties in the northwestern portion of Colorado. At all these places there are large quantities of the impregnated rock but it contains on the average only about 1.5 per cent to 2 per cent of U_3O_8. The mineral has also been described from Mt. Pisgah, Mauch Chunk, Pennsylvania, and from Radium Hill, South Australia.

Uses.—The mineral is one of the main sources of radium and uranium and is one of the principal sources of vanadium. Although it contains a notable quantity of uranium, carnotite has little value except as an ore of radium and vanadium, because of the few uses to which uranium is put. This metal is used to some extent in making steel alloys and in the manufacture of iridescent glazes and glass. Its compounds are used in certain chemical determinations, as medicines, in photography, as porcelain paint, and as a dye in calico printing. The uses of vanadium have been referred to on p. 273.

The principal value of carnotite depends upon its content of radium, which in the form of the chloride is valued at about $40,000 per gram or $1,500,000 per oz. The importance of radium as a therapeutic agent has not been established; but that its use is wonderfully helpful in many diseases is beyond question. Without doubt in the near future carnotite will become the principal source of radium in the world. Practically the only other source is the pitchblende (p. 297), of Gilpin, Colorado, Cornwall, England and Joachimsthal, Austria.

Production.—Carnotite has been mined in San Miguel and Montrose Counties, Colorado, and at several points in eastern Utah, but mainly for the vanadium it contains. At present it is being utilized as a source of radium. From Colorado 8,400 tons of vanadium ore, with a value of $302,000, were shipped in 1911 and from New Mexico and Utah about 70 tons, valued at $3,500. Some of this, however, was vanadinite. Most of it was exported and used as a source of vanadium. However, the uranium content of the carnotite mined was about 1.1 tons of the metal. During 1912 ore containing 26 tons of uranium oxide and 6.7 grams of radium was produced. This would have yielded 11.43 grams of radium bromide, valued at $52,800. The present price of standard carnotite carrying at least 2 per cent U_3O_8 and 5 per cent V_2O_5, is at the rate of $1.25 per lb. for the former and thirty cents for the latter. In 1914 the selling price of 4,294 tons of carnotite ore containing 87 tons of U_3O_8 was $103 per ton. At the present time nothing is paid for the radium content of the ore, though this is its most valuable component. One ton of ore containing 1 per cent of U_3O_8 carries 2.566 milligrams of radium. The imports of uranium compounds during 1912 were valued at $14,357.

HYDRATED ACID PHOSPHATES AND ARSENATES

A number of hydrated acid phosphates and arsenates are known to constitute an isomorphous group, but only a few of them occur as minerals. *Brushite* is an acid calcium phosphate and *pharmacolite* is the corresponding arsenate. Both crystallize in the monoclinic system (prismatic class). Neither is common.

Pharmacolite ($HCaAsO_4 \cdot 2H_2O$) occurs principally in silky fibers, in botryoidal and stalactic masses and rarely in crystals with an axial ratio .6236 : 1 : .3548 and $\beta = 83° 13'$. Their cleavage is perfect parallel to $\infty P \bar{\infty}$ (010). The mineral is white or gray, tinged with red. Its streak is white. It is translucent or opaque. Its luster is vitreous, except on $\infty P \bar{\infty}$ (010) where it is slightly pearly. Thin laminae are flexible. Its hardness is 2–2.5 and density 2.7. Its refractive indices for yellow light are: $\alpha = 1.5825$, $\beta = 1.5891$, $\gamma = 1.5937$.

Before the blowpipe pharmacolite swells up and melts to a white enamel. The mineral gives the usual reactions for As, H_2O and Ca. It usually occurs in the weathered zone of arsenical ores of Fe, Ag and Co, at Andreasberg, Harz; Joachimsthal, Bohemia, and elsewhere.

CHAPTER XV

THE COLUMBATES, TANTALATES AND URANATES

THE rare metals, columbium and tantalum, exist in a few silicates, but their principal occurrences are as columbates and tantalates which are salts of columbium and tantalum acids, analogous to the various acids of sulphur. The commonest compounds are salts of the meta-acids $H_2Cb_2O_6$ and $H_2Ta_2O_6$, the relations of which, to the normal acids, are indicated by the equation $2H_3CbO_4 - 2H_2O = H_2Cb_2O_6$. Other important minerals are derivatives of the pyroacids corresponding to $H_4Cb_2O_7$, or $2H_3CbO_4 - H_2O$. The best known ortho salt is *fergusonite*, $YCbO_4$, but it is rare.

All the columbates yield a blue solution when partially decomposed in H_2SO_4 and boiled with HCl and metallic tin. The tantalates when fused with $KHSO_4$ and treated with dilute HCl give a yellow solution and a heavy white precipitate, which, on treatment with metallic zinc or tin, assumes a deep blue color. When diluted with water the blue color of the tantalate solution disappears, while that of the columbate solution remains.

The uranates are salts of uranic acid, H_2UO_4. The only mineral known that may be a uranate is *uraninite*, and the composition of this is doubtful.

Columbite ($(Fe \cdot Mn)Nb_2O_6$) and Tantalite ($(Fe \cdot Mn)Ta_2O_6$)

These two minerals are isomorphous mixtures of iron and manganese columbates and tantalates. The name *columbite* is applied to the mixture that is composed mainly of the columbates, and *tantalite* to that which is principally a mixture of tantalates. When the tantalite is composed almost exclusively of the manganese molecule, it is known as *manganotantalite*. Tin and tungsten are frequently found in both minerals.

Their crystals are orthorhombic, with $a : b : c = .8285 : 1 : .8898$ for the nearly pure columbium compound, and $.8304 : 1 : .8732$ for the nearly pure tantalum compound. Both form short prismatic crystals containing many faces, among the most prominent being the three pinacoids; various prisms, notably $\infty P(110)$, $\infty P\breve{3}(130)$ and $\infty P\breve{6}(160)$,

and the domes $2P\bar{\infty}$ (201) and $\frac{1}{2}P\breve{\infty}$ (012) (Fig. 161). The most prominent pyramids are P(111) and $P\breve{3}$(133). Twins are not uncommon, with $2P\bar{\infty}$ (201) the twinning plane. The angle $110 \wedge 1\bar{1}0$ for columbite $= 79° 17'$.

Both minerals are usually opaque, black and lustrous, and occasionally iridescent, though, in some instances, they are translucent and brown. Their streak is dark red or black. Their cleavage is distinct parallel to $\infty P\bar{\infty}$ (100), fracture uneven or conchoidal, their hardness 6 and their specific gravity between 5.3 and 7.3, increasing with the proportion of the tantalum molecules present. They are both infusible before the blowpipe. Some specimens exhibit weak radioactivity.

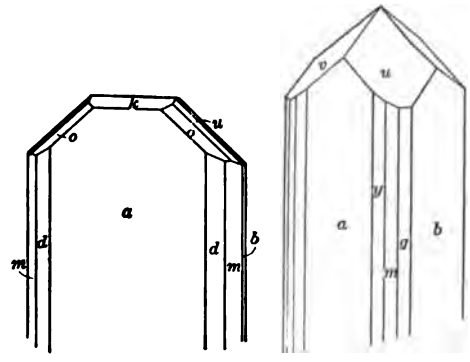


FIG. 161.—Columbite Crystals with $\infty P\bar{\infty}$, 100 (*a*); $\infty P\breve{\infty}$, 010 (*b*); ∞P, 110 (*m*); $\infty P\bar{2}$, 210 (*y*); $\infty P\frac{7}{3}$, 730 (*d*); $\infty P\breve{3}$, 130 (*g*); $\frac{1}{2}P\bar{\infty}$, 103 (*k*); P, 111 (*o*) and $P\breve{3}$, 133 (*u*).

When columbite is decomposed by fusion with KOH and dissolved in HCl and H_2SO_4, the solution turns blue on the addition of metallic zinc. The mineral is also partially decomposed when evaporated to dryness with H_2SO_4, forming a white compound that changes to yellow. When this residue is boiled with HCl and metallic zinc a blue solution results. The mineral also gives reactions for iron and manganese.

Tantalite is decomposed upon fusion with $KHSO_4$ in a platinum spoon, or on foil. This when heated with dilute HCl yields a yellow solution and a heavy white powder. Upon addition of metallic zinc, a blue color results and this disappears on dilution with water. In the microcosmic salt bead tantalite dissolves slowly, giving reactions for iron and manganese. When treated with tin on charcoal the bead turns green.

The two minerals may easily be confused with black *tourmaline* (p. 434), *ilmenite* (p. 462) and *wolframite*. From tourmaline, they are distinguished by crystallization, high specific gravity and luster; from wolframite by their less perfect cleavage and by the reaction with aqua regia (see p. 259); from ilmenite by the test for titanium.

Occurrence, Origin and Localities.—Both minerals occur in veins of coarse granite and probably have a pneumatolytic origin.

Columbite is found in granite veins at Bodenmais, Bavaria; Tammela, in Finland; near Limoges, France, with tantalite; near Miask, in the Ilmen Mountains, Russia, with samarskite; and at Ivigtut, in Greenland. In the United States it is found at Standish and Stoneham, in Maine; at Acworth, in New Hampshire; at Haddam, in Connecticut; at Amelia Court House, Virginia; with samarskite in the mica mines in Mitchell County, North Carolina; in the Black Hills, South Dakota, and at a number of other points in New England and the Far West.

Tantalite is found at many of the localities for columbite and also at several other places in Finland; near Falun, in Sweden; in Yancy County, North Carolina, and in Coosa County, Alabama.

Uses.—At the present time columbium and its compounds have no commercial uses. Tantalum, however, is employed in the manufacture of filaments for certain types of incandescent lamps. Since, however, about 20,000 filaments may be made from a single pound of the metal the market for tantalum ores is very limited.

Samarskite and Yttrotantalite

These two minerals may be regarded as isomorphous mixtures of salts of pyrocolumbic and pyrotantalic acids, in which the bases are yttrium, iron, calcium and uranyl.

Samarskite, according to this view, is approximately

$$Y_2(Ca \cdot Fe \cdot UO_2)_3(Nb_2O_7)_3$$

and yttrotantalite the corresponding tantalate. Yttrium and iron are the principal bases, but there are also often present erbium, cerium, tungsten and tin.

Analyses made by Rammelsberg and quoted by Dana give some idea of the complexity of the compounds:

	Density	Ta_2O_5	Nb_2O_5	WO_3	SnO_2	TiO_2*	Y_2O_3	Er_2O_3
I.	5.425	46.25	12.32	2.36	1.12	....	10.52	6.71
II.	5.839	14.36	41.07		.16	.56	6.10	10.80
III.	5.672	.....	55.34		.22	1.08	8.80	3.82

	Ce_2O_3†	UO_2	FeO	CaO	H_2O	Total
I.	2.22	1.61	3.80	5.73	6.31	98.95
II.	2.37	10.90	14.61	....	....	100.93
III.	4.33	11.94	14.30	....	....	99.83

I. From Itterby, Sweden. II. From North Carolina. III. From Miask, Russia.

* Including SiO_2. † Including Di_2O_3 and La_2O_3.

The first of these three minerals has been called yttrotantalite and the other two samarskite. If the first is weathered, as seems probable from the presence of over six per cent of water, the three may constitute members of an isomorphous series with the third representing the nearly pure columbate (samarskite), the first a compound in which the tantalate molecule is in excess (yttrotantalite), and the second an intermediate compound which contains both the tantalum and columbium molecules, with the latter predominating.

With more accurate analyses the great complexity of these compounds becomes even more apparent. Hillebrand has given the following report of his analysis of a samarskite from Devil's Head Mountain, near Pike's Peak, Colorado, which shows the futility of attempting to represent its composition by a chemical formula:

	Pitch-black Variety	Black Variety	Weathered Variety
Ta_2O_5	27.03	28.11	19.34
Cb_2O_5	27.77	26.16	27.56
WO_3	2.25	2.08	5.51
SnO_2	.95	1.09	.82
ZrO_2	2.29	2.60	3.10*
UO_2	4.02	4.22	....
UO_3	...	...	6.20
ThO_2	3.64	3.60	3.19
Ce_2O_3	.54	.49	.41
$(La,Di)_2O_3$	1.80	2.12	1.44
Er_2O_3	10.71	10.70	9.82
Y_2O_3	6.41	5.96	5.64
Fe_2O_3	8.77	8.72	8.90
FeO	.32	.35	.39†
MnO	.78	.75	.77
ZnO	.05	.07	
PbO	.72	.80	1.07
CaO	.27	.33	1.61
MgO	....	...	.11
K_2O	.17	.13	.36
$(Na,Li)_2O$	.24	.17	
H_2O	1.58	1.30	3.94
F	?	?	?
Total	100.31	99.75	100.18
Sp. gr.	6.18	6.12	5.45

* With TiO_2. † Or 0.74 UO_2.

Both samarskite and yttrotantalite are orthorhombic, with an axial ratio for samarskite of .5456 : 1 : .5178, and for yttrotantalite, .5411 : 1 : 1.1330. They, however, more commonly occur massive and in flattened grains embedded in rocks. Their crystals are prismatic in the direction of the *c* or the *b* axis. Their most prominent forms are $\infty P \bar{\infty}$ (100), $\infty P \breve{\infty}$ (010) and $P \bar{\infty}$ (101) (Fig. 162). Less prominent but fairly common are $\infty P \breve{2}$(120), ∞P(110), P(111) and $3P\frac{3}{2}$(231). The angle $110 \wedge 1\bar{1}0$ for samarskite is 57° 14′ and for yttrotantalite 56° 50′.

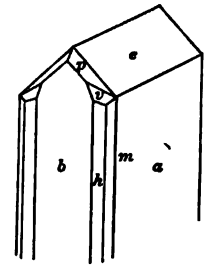


FIG. 162.—Samarskite Crystal with $\infty P \bar{\infty}$, 100 (*a*); $\infty P \breve{\infty}$, 010 (*b*); ∞P, 110 (*m*); $\infty P \breve{2}$, 120 (*h*); $P \bar{\infty}$, 101 (*e*); P, 111 (*p*); $3P\frac{3}{2}$, 231 (*v*).

The cleavage of both minerals is indistinct parallel to $\infty P \breve{\infty}$ (010). Their fracture is conchoidal. Both are brittle. The hardness of samarskite is 5–6, its density about 5.7, its luster vitreous, its color velvety black and its streak reddish brown. Yttrotantalite is a little softer (5–5.5). Its specific gravity is 5.5–5.9, its luster submetallic to vitreous, its color black, brown, or yellow, and its streak gray to colorless. Samarskite is opaque and yttrotantalite opaque or translucent.

The reactions of the minerals vary with their composition. They always yield the blue solution test for tantalum or columbium, and most specimens react for Mn, Fe, Ti and U. The reaction for uranium is an emerald green bead with microcosmic salt in both reducing and oxidizing flame.

They are distinguished from *columbite* and *tantalite* by the form of their crystals.

Occurrence.—The two minerals, like columbite and tantalite, are found principally in pegmatite veins and in many of the same localities. Yttrotantalite occurs mainly at Ytterby and near Falun, in Sweden, and samarskite, near Miask in the Ilmen Mountains, Russia. In the United States the last-named mineral is sometimes found in large masses in the mica pegmatites of Mitchell County, North Carolina.

Uses.—Neither mineral is at present of any commercial value. They are, however, extremely interesting as the source of many of the rare elements, and, especially, as a possible source of radium and closely related substances.

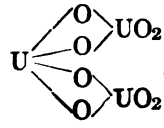
Uraninite

Uraninite, or pitchblende, like the other compounds containing the element uranium, is of doubtful composition. It contains so many

different components that a correct conception of its character is almost impossible to grasp. The mineral is particularly interesting because it always contains a trace of radium, of which it is an important commercial source at the present time.

Analyses of crystallized material (I) from Branchville, Conn., and from Anneröd (II), Norway, gave the following results:

	UO_3	UO_2	ThO_2	PbO	Fe_2O_3	CaO	H_2O	He	Insol.
I.	21.54	64.72	6.93	4.34	.28	.22	.67	Und.	.14
II.	30.63	46.13	6.00	9.04	.25	.37	.74	.17	4.42

with small quantities also of ZrO_2, CeO_2, La_2O_3, Di_2O_3, Y_2O_3, Er_2O_3, MnO, Alkalies, SiO_2 and P_2O_5. These analyses are interpreted as indicating that the mineral is a uranium salt of uranic acid, $UO_2(OH)_2$, or H_2UO_4, thus  , or U_3O_8, in which Pb replaces the U in part, and ThO_2 the UO_2. Radium is found in most specimens and helium in nearly all.

Several varieties are recognized, the distinctions being based largely upon chemical differences.

Bröggerite has UO_3 to other bases as 1 : 1.

Cleveite and *nivenite* contain 9 per cent to 10 per cent of the yttria earths.

Pitchblende is possibly an amorphous uraninite containing a very little thoria and much water. Its specific gravity is often as low as 6.5, due probably to partial alteration.

Uraninite crystallizes in the isometric system in octahedrons, and in combinations of O(111), ∞ O(110), and ∞ O ∞ (100). Crystals are rare, however, the material usually occurring in crystalline masses and in botyroidal groups.

The mineral is gray, brown or black and opaque. Its streak is brownish black, gray or olive green. Its luster is pitch-like or dull. Its fracture is uneven or conchoidal. It is brittle, its hardness is 5.5 and density 9–9.7. Like the other uranium minerals it is radioactive.

Before the blowpipe uraninite is infusible. Some specimens color the flame green with copper. With borax it gives a yellow bead in the oxidizing flame, turning green in the reducing flame. All specimens give reactions for lead and many for sulphur and arsenic. The mineral is soluble in nitric and sulphuric acids, with slight evolutions of helium,

the ease of solubility increasing with the increase in the proportion of rare earths present.

Uraninite is distinguished from *wolframite, samarskite, columbite* and *tantalite*, by lack of cleavage, greater specific gravity, and differences in crystallization. From all but samarskite it is also distinguished by the reactions for uranium and, in the case of most specimens, by the reaction for lead. It is especially characterized by its pitch-black luster.

Occurrence and Localities.—Uraninite occurs in pegmatites and in veins associated with silver, lead, copper and other ores. It is found in the ore veins in Saxony, Bohemia, and in pegmatites near Moss, Arendal and other points in Norway.

In the United States it occurs in pegmatites at Middletown and Branchville, in Connecticut; at the Mitchell County mica mines, North Carolina; and at Barringer Hill, Llano County, Texas. It is also found in large quantity near Central City, Gilpin County, Colorado, where it is associated with gold, galena, tetrahedrite, chalcopyrite and other ore minerals.

Production.—Uraninite has been mined in small quantity in Colorado, and at Barringer Hill, both as a source of uranium and as a source of radium. In Cornwall, England, and at Joachimsthal, Austria, it is mined as a source of radium. (See also p. 292.)

CHAPTER XVI

THE SILICATES

THE silicates are salts of various silicon acids, only a few of which are known uncombined with bases. The silicates include the commonest minerals and those that occur in largest quantity. They make up the greater portion of the earth's crust, forming most of the igneous rocks and a large portion of vein fillings. In number, the silicates exceed all other mineral compounds, but because of their stability they are of very little economic importance. A few are used as the sources of valuable substances, and their aggregates, the silicious rocks, are utilized as building stones, but, on the whole, they are of little commercial value. Since, however, they occur in good crystals and their material is transparent in thin sections so that it can easily be studied by optical methods, they are of great scientific importance. Much of the progress made in crystallography has been accomplished through the study of these compounds.

Although the salts of the silicic acids are very numerous and most of them are very stable toward the ordinary reagents of the laboratory, the acids from which they are derived are only imperfectly known. The only one that has been prepared in the pure state is the compound H_2SiO_3. This occurs as a gelatinous (colloidal) white substance which rapidly loses water upon drying and probably breaks up into a number of other compounds which are also acids, containing, however, a larger proportion of silicon in the molecule than that in the original compound. When the tetrafluoride, or the tetrachloride, of silicon is decomposed by water, the principal product is the acid referred to above, but in addition to this there is probably formed also the compound H_4SiO_4 or $Si(OH)_4$, which is the ortho acid. Some silicates are salts of these acids. Others are salts of the acids containing a larger proportion of silicon. In most cases, however, these acids may be regarded as belonging to a series in which the members are related to one another in the same manner as are normal sulphuric, common sulphuric and pyrosulphuric acids. Normal sulphuric acid is H_6SO_6. By abstraction of $2H_2O$ the compound H_2SO_4, or ordinary sulphuric acid, results. If from two molecules of H_2SO_4, one molecule of H_2O is abstracted, $H_2S_2O_7$, or pyrosulphuric acid, is left. In the same manner all of the silicic acids may be regarded

as being derived from normal silicic acid $Si(OH)_4$ or H_4SiO_4 by the abstraction of water, thus:

Orthosilicic acid is	H_4SiO_4,
Metasilicic acid is	$H_4SiO_4 - H_2O$ or H_2SiO_3,
Diorthosilicic acid is	$2H_4SiO_4 - H_2O$ or $H_6Si_2O_7$,
Dimetasilicic acid is	$2H_2SiO_3 - H_2O$ or $H_2Si_2O_5$,
Trimetasilicic acid is	$3H_2SiO_3 - H_2O$ or $H_4Si_3O_8$.

The compounds containing more than one silicon atom in the molecule are known as polysilicates. The salts of metasilicic acid are metasilicates.

Many attempts have been made to discover the chemical structure of the comparatively simple silicates and several proposals have been offered to explain the great differences often observed in the properties of silicates with the same empirical formula; but no explanation of these differences has thus far proved satisfactory. The silicates are so very stable under laboratory conditions, and, when they are decomposed, their decomposition products are so difficult to study, that it has been impossible to determine their molecular volumes or to understand their substitution products. We are thus driven to ascribe many of the anomalies in their composition to solid solutions, to absorption phenomena, and to the isomorphous mixing of compounds, some of which do not exist independently.

There are many silicates, moreover, which cannot be assigned to any of the simple acids mentioned above, but which probably must be regarded as salts of very much more complex acids. Others are possible salts of aluminosilicic acids in which aluminium functions in the acid portions. Thus, albite is usually regarded as a trisilicate, $NaAlSi_3O_8$, and anorthite as an orthosilicate, $CaAl_2(SiO_4)_2$. But the two substances are completely isomorphous, and for this reason it is thought that they must be salts of the same acid. If we assume an aluminosilicic acid of the formula $H_5AlSi_2O_8$, albite may be written $(NaSi)AlSi_2O_8$, and anorthite $(CaAl)AlSi_2O_8$. The two minerals thus become salts of the same acid and their complete isomorphism is explained. The relations that exist among many silicates might be better understood on the assumption that they are salts of complex silicic and of aluminosilicic acids than on the assumption that they are salts of simpler acids, as is now the case. But, since it has been impossible to isolate the acids and study them we are not certain as to their character. It is, therefore, believed best to represent most silicates as salts of the simplest acids possible, consistent with their empirical compositions as determined by analyses.

As in the case of salts of other acids there are silicates that contain hydrogen and oxygen in such relations to their other components that when heated they yield water. In some cases this water is driven off at a comparatively low temperature and the residue of the compound remains unchanged. A compound of this kind is usually called a hydrate or the compound is said to contain water of crystallization. In other cases a high temperature is necessary to drive off water, and the compound breaks up into simpler ones. In these instances the water is said to be combined. The compound is usually basic.

In the descriptions of the silicates the order in which the minerals are discussed is that of increasing acidity, i.e., increasing proportion of the SiO_2 group present in the molecule. This order, however, is not followed rigorously. The members of well defined groups of closely related minerals are discussed together even if their acidity varies widely. Nearly all the silicates are transparent or translucent and all are electrical insulators.

THE ANHYDROUS ORTHOSILICATES

NORMAL ORTHOSILICATES—R_4SiO_4

OLIVINE GROUP (R''_2SiO_4). R'' = Mg, Fe, Mn, Zn

The members of the olivine group are normal silicates of the metals Mg, Fe, Mn and Zn. They constitute an isomorphous series crystallizing in the holohedral division of the orthorhombic system (rhombic bipyramidal class). The most common member is the magnesium-iron compound $(Mg \cdot Fe)_2SiO_4$, *olivine*, or *chrysot.le*, from which the group gets its name. The members with the simplest composition are *forsterite* (Mg_2SiO_4), *fayalite* (Fe_2SiO_4) and *tephroite* (Mn_2SiO_4). The others are isomorphous mixtures of these, with the exception of three rare minerals, of which one, *monticellite*, is a calcium magnesium silicate, another, *titanolivine*, contains Ti in place of a part of the Si, and the other, *roepperite*, contains some Zn_2SiO_4. Most of them are formed by crystallization from molten magmas.

Crystals of all the members of the group are prismatic and all have nearly the same habit. They are often flattened parallel to one of the pinacoids, $\infty P \breve{\infty}$ (010) or $\infty P \bar{\infty}$ (100). The axial ratios of the commoner members are as follows:

Forsterite	$a : b : c = .4666 : 1 : .5868$.	The angle $110 \wedge 1\bar{1}0 = 50° 2'$
Olivine	$= .4658 : 1 : .5865$.	The angle $110 \wedge 1\bar{1}0 = 49° 57'$
Tephroite	$= .4600 : 1 : .5939$.	The angle $110 \wedge 1\bar{1}0 = 49° 24'$
Fayalite	$= .4584 : 1 : .5793$.	The angle $110 \wedge 1\bar{1}0 = 49° 15'$

Crystals of olivine are usually combinations of some or all of the following forms: $\infty P\bar{\infty}$ (100), $\infty P\breve{\infty}$ (010), oP(001), ∞P(110), $\infty P\breve{2}$(120), $P\breve{\infty}$ (011), $2P\breve{\infty}$ (021), $P\bar{\infty}$ (101), P(111) and $2P\breve{2}$(121) (Fig. 163). The crystals of fayalite are usually more tabular than those of olivine, but forsterite and tephroite crystals have nearly the same forms. The cleavage of all is distinct parallel to $\infty P\breve{\infty}$ (010), less distinct parallel to $\infty P\bar{\infty}$ (100) in olivine, and parallel to oP(001) in fayalite.

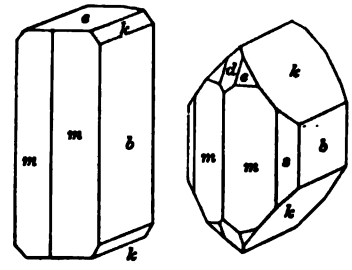


FIG. 163.—Olivine Crystals with ∞P, 110 (*m*); $\infty P\breve{\infty}$, 010 (*b*); oP, 001 (*c*); $2P\breve{\infty}$, 021 (*k*); $\infty P\breve{2}$, 120 (*s*), $P\bar{\infty}$, 101 (*d*) and P, 111 (*e*).

The compositions of the pure Mg, Mn, and Fe molecules are:

	Mg_2SiO_4	Mn_2SiO_4	Fe_2SiO_4
MgO	57.1		
MnO	....	70.25	
FeO	....	.....	70.6
SiO_2	42.9	29.75	29.4

All natural crystals, however, contain some of all the metals indicated and, in addition, many specimens contain also a determinable quantity of CaO and traces of other elements.

Forsterite, Olivine and Fayalite ($Mg_2SiO_4 - (Mg \cdot Fe)_2SiO_4 - Fe_2SiO_4$)

The composition of olivine naturally depends upon the proportion of the forsterite and fayalite molecules present in it. When the proportion of FeO exceeds 24 per cent, the variety is known as *hyalosiderite*. A few typical analyses are quoted below:

	MgO	FeO	CaO	Al_2O_3	SiO_2	Total	Sp. Gr.
I.	51.64	5.01	1.08	.42	42.30	100.45	3.261
II.	50.27	8.54	....	...	41.19	100.00	
III.	48.12	11.18	.12	...	40.39	99.81	3.294
IV.	39.68	22.54	....	...	37.17	99.39	

I. From masses enclosed in Vesuvian lava.
II. Concretion in basalt near Sasbach, Kaiserstuhl.
III. Grains from glacial debris, Jan Mayen, Greenland.
IV. Grains from coarse-grained rock, near Montreal, Canada.

In addition, there are often also present small quantities of Ni, Mn, and Ti.

Forsterite, olivine and fayalite are usually yellow or green in color and have a vitreous luster. Forsterite is sometimes white and olivine often brown. All three minerals become brown or black on exposure to the air. All are transparent or translucent. Their streak is colorless or yellow. The fracture of olivine is conchoidal. In the other two minerals it is uneven. Their hardness, density and refractive indices for yellow light are as follows:

	Hardness	Sp. Gr.	α	β	γ
Forsterite.....	6–7	3.21–3.33	1.6319	1.6519	1.6698
Olivine.....	6.5–7	3.27–3.37	1.6674	1.6862	1.7053
Fayalite.....	6.5	4.00–4.14	1.8236	1.8642	1.8736

Before the blowpipe most olivines and forsterites whiten but are infusible. Their fusion temperatures are between 1300° and 1450°, decreasing with increase in iron. Fayalite and varieties of olivine rich in iron fuse to a black magnetic globule. All three minerals are decomposed by hydrochloric and sulphuric acids with the separation of gelatinous silica; the iron-rich varieties are decomposed more easily than those poor in iron.

The minerals are characterized by their color and solubility in acids.

Both fayalite and olivine alter on exposure to the air, the former changing to an opaque mixture of Fe_2O_3 and SiO_2, or to the fibrous mineral anthophyllite ($(Mg \cdot Fe)SiO_3$), and olivine to a mixture of iron oxides and fibrous or scaly gray or green serpentine ($H_4Mg_3Si_2O_9$). In other cases, under metamorphic conditions, the alteration is to a red lamellar mineral (*iddingsite*) which may be a form of serpentine, or to magnesite, or to the silicate, talc. Other kinds of alteration of this mineral have also been noted but those described are the most common.

Syntheses.—The members of the olivine series have been produced by fusing together the proper constituents in the presence of magnesium and other chlorides. They are, moreover, present in many furnace slags where they have been made in the process of ore smelting.

Occurrence.—Olivine occurs as an original constituent of basic igneous rocks and as a metamorphic product in dolomitic limestones. It is found also in the form of rounded grains in some meteoric irons. Fayalite occurs in acid igneous rocks, especially where affected by pneumatolytic

action, and forsterite in dolomitic rocks when they have been metamorphosed by the action of igneous rocks.

Localities.—Members of the olivine group occur in the basaltic lavas of many volcanoes—as those of the Sandwich Islands; in the limestone inclusions in the lava of Mt. Somma, near Naples; in various basic rocks in Vermont and New Hampshire and at Webster, N. C. At the latter place granular aggregates of almost pure olivine constitute great rock masses known as *dunite.*

Fayalite is found in the rhyolites of Mexico, the Yellowstone Park and elsewhere, and in coarse granite at Rockport, Mass., and in the Mourne Mountains, Ireland.

Forsterite occurs in limestone enclosures in the lava of Mt. Somma and at limestone contacts with igneous rocks at Bolton, Roxbury, and Littleton, Mass., and elsewhere.

Uses and Production.—The only member of the group that is of any economic importance is a pale yellowish green transparent olivine, which is used as jewelry under the name of "peridot." Gem material is found at Fort Defiance and Rice, in Arizona, scattered loose in the soil. The little grains came from a basic volcanic rock. The amount produced in the United States during 1912 was valued at about $8,100.

Tephroite (Mn_2SiO_4)

Although tephroite is regarded as the manganese silicate it nearly always contains some of the forsterite molecule.

Analyses of brown (I), and red (II), varieties from Sterling Hill gave:

	MnO	FeO	MgO	CaO	ZnO	Loss	SiO_2	Total
I.	52.32	1.52	7.73	1.60	5.93	.28	30.55	99.93
II.	47.62	.23	14.03	.54	4.77	.35	31.73	99.27

The mineral is gray, brown or rose-colored and transparent or translucent. Its streak is nearly colorless. It is rarely found in crystals. Its hardness is about 6 and its density 4.08. It is strongly pleochroic in reddish, brownish red and greenish blue tints. Its intermediate refractive index for yellow light = about 1.80.

It is fusible with difficulty (fusing temperature = 1200°), and is soluble in HCl with separation of gelatinous silica. It is distinguishable from other like-appearing minerals by its difficult fusibility and its reaction with HCl.

Syntheses.—Crystals of the mineral have been made by fusing together SiO_2 and MnO_2 in the proportion of 1 : 2, and by long-continued

heating of $MnCl_2$ and SiO_2 in an atmosphere of moist hydrogen or carbon dioxide.

Localities.—Tephroite occurs at Mine Hill and Sterling Hill, near Franklin, N. J., where it is associated with franklinite, zincite and troostite. It is found also at Pajsberg in Sweden with other manganese minerals and magnetite, and at Langban, in Wermland, Sweden.

Uses.—The mineral is of little commercial value. It is separated with other manganese minerals from the zinc ore of Franklin, N. J., and is smelted with these in the production of spiegeleisen.

WILLEMITE GROUP ($R_2''SiO_4$). R''=Zn, Mn.

The willemite group comprises the two minerals *willemite* (Zn_2SiO_4) and *troostite* ($(Zn \cdot Mn)_2SiO_4$), of which the latter is rare. Willemite occurs in small quantity only, but troostite is an important source of zinc at the Franklin locality in New Jersey. Both minerals are found in crystals.

Willemite and troostite crystallize in the rhombohedral hemihedral division of the hexagonal system (ditrigonal scalenohedral class), with the axial ratios

Willemite	$a : c = 1 : 0.6698$
Troostite	$= 1 : 0.6698$

Willemite and Troostite ($Zn_2SiO_4 - (Zn \cdot Mn)_2SiO_4$)

Willemite and troostite occur massive, in grains, and in simple crystals.

The theoretical composition of willemite is $SiO_2 = 27.04$ and $ZnO = 72.96$, but nearly all natural crystals contain traces of other elements. When a noticeable quantity of manganese is present, the compound is troostite. Several analyses are quoted below:

	SiO_2	ZnO	MnO	FeO	Total
Willemite from Stolberg, Germany.....	26.90	72.91	....	.35	100.16
Willemite from Greenland.....	27.86	71.51	....	.37	99.74
White troostite from Franklin, N. J....	27.20	65.82	6.97	.23	100.22
Dark red troostite from Franklin, N. J..	27.14	64.38	6.30	1.24	99.06

The crystals of willemite exhibit the forms $\infty R(10\bar{1}0)$, $\infty P2(11\bar{2}0)$, $oR(0001)$, $\frac{3}{4}R(30\bar{3}4)$ and $-\frac{1}{2}R(01\bar{1}2)$(Fig.164). Twins, with $\frac{3}{5}P2(3.3.6.10)$ as the twinning planes, are rare. The crystals of troostite are even more simple, with $\infty P2(11\bar{2}0)$ and $R(10\bar{1}1)$, usually the only forms

present, though $-\frac{1}{2}R(01\bar{1}2)$, $-\frac{3}{2}R(03\bar{3}2)$ and $R^3(21\bar{3}1)$ are also occasionally found. The angle $10\bar{1}1 \wedge \bar{1}101 = 63° 59'$. The cleavage of willemite is distinct parallel to oP(0001), and of troostite distinct parallel to $\infty P2(11\bar{2}0)$, and less perfect parallel to $R(10\bar{1}1)$ and oR(0001).

Willemite is colorless, yellow, brown or blue. Troostite is green, yellow, brown or gray. The colored varieties of both minerals are translucent. Colorless willemite is transparent. Both minerals are vitreous in luster. Their hardness is between 5 and 6 and density between 3.9 and 4.3. The refractive indices of willemite for yellow light are: $\omega = 1.6931$, $\epsilon = 1.7118$.

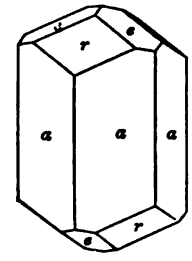


FIG. 164.—Willemite Crystal with $\infty P2$, $11\bar{2}0$ (*a*); R, $10\bar{1}1$ (*r*) and $-\frac{1}{2}R$, $01\bar{1}2$ (*e*).

Both minerals glow when heated before the blowpipe and are fused with difficulty (about 1484°), and both gelatinize with HCl. Willemite gives the reaction for zinc with $Co(NO_3)_2$ on charcoal, and troostite gives, in addition, the reaction for manganese.

Syntheses.—Willemite crystals have been made by the action of gaseous hydrofluosilicic acid upon zinc, and by the action of silicon fluoride on zinc oxide at cherry-red temperature.

Localities and Origin.—Willemite occurs in comparatively small quantity at only a few places, associated with other zinc minerals. In America it is found in colorless and black crystals at the Merritt Mine near Socorro, New Mexico, associated with mimetite, wulfenite, cerussite, barite and quartz.

Troostite occurs only at Sterling Hill and Franklin Furnace, N. J., but in such large quantity that it constitutes an important proportion of the zinc ore for which these localities are noted. It is associated with franklinite and zincite. Both willemite and troostite are results of magmatic processes.

Phenacite (Be_2SiO_4)

The theoretical composition of the compound Be_2SiO_4 is $SiO_4 = 54.47$, $BeO = 45.53$. Many of the analyses of phenacite show that it approaches very closely to this. A specimen from Durango, Mexico, for example, is:

$$SiO = 54.71,\ BeO = 45.32,\ MgO + CaO = .14.\quad \text{Total} = 100.17.$$

Phenacite crystallizes in the rhombohedral tetartohedral division of the hexagonal system with $a : c = 1 : 1.0661$. It occurs in crystals possessing many different types of habit and with many different combinations of forms. Perhaps $\infty P2(11\bar{2}0)$, $\infty P(10\bar{1}0)$, $R(10\bar{1}1)$, $R^3(21\bar{3}1)$ and $-\frac{1}{2}R(01\bar{1}2)$ are the most common (Fig. 165). Interpenetration twins are common at some localities. The cleavage is indistinct parallel to $\infty P(10\bar{1}0)$. The angle $10\bar{1}1 \wedge \bar{1}101 = 63° 24'$.

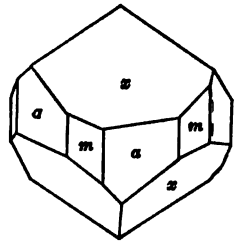


FIG. 165.—Phenacite Crystal with $\infty P2$, $11\bar{2}0$ (a); ∞P, $10\bar{1}0$ (m) and $\frac{-\frac{1}{2}P3}{2}r$, $\bar{1}3\bar{2}2$ (x).

Phenacite is colorless or white or some light shade of yellow or pink. It is transparent or translucent and has a glassy luster. Its hardness is 7.5, and density about 3 and the refractive indices for yellow light are: $\omega = 1.6542$, $\epsilon = 1.6700$. It is infusible and insoluble in acids. When heated with a little soda before the blowpipe it affords a white enamel. The mineral is phosphorescent and pyroelectric.

Colorless phenacite resembles *quartz* and *herderite*, and the yellow variety topaz. It is best distinguished from them by its crystallization.

Syntheses.—Small crystals have been made by the fusion of a mixture of SiO_2 and beryllium oxide and borax, and by melting together beryllium nitrate, silica and ammonium nitrate.

Localities.—Phenacite occurs at the Emerald Mines near Ekaterinburg in the Urals; near Fremont, in the Vogesen; at Reckingen, in Switzerland; in Durango, Mexico; near Pike's Peak, at Topaz Butte, and at Mount Antero, in Colorado, and at Greenwood, in Maine. In all cases the mineral is probably a result of pneumatolysis.

Uses.—The colorless phenacite is used to a slight extent as a gem.

GARNET GROUP

$(R''_3R'''_2(SiO_4)_3)$. $R'' = Ca, Mg, Fe, Mn$. $R''' = Al, Fe, Cr$

The garnet group comprises a large number of isomorphous compounds, some of which are very common. The members nearly all occur in distinct crystals that are combinations of isometric holohedrons (hexoctahedral class). Many different names have been given to the garnets and analyses show that they possess very different compositions. With the exception of a few rare varieties, they can all, however, be explained as consisting of one of the six molecules indicated below, or of

mixtures of them. The six molecules and the names of the garnets corresponding to them, together with their densities, are:

$Ca_3Al_2(SiO_4)_3$	*Grossularite or Hessonite*	Sp. gr. = 3.4–3.6
$Mg_3Al_2(SiO_4)_3$	*Pyrope*	= 3.7–3.8
$Mn_3Al_2(SiO_4)_3$	*Spessartite*	= 4.1–4.3
$Fe_3Al_2(SiO_4)_3$	*Almandite*	= 4.1–4.3
$Ca_3Fe_2(SiO_4)_3$	*Andradite or Melanite*	= 3.8–4.1
$Ca_3Cr_2(SiO_4)_3$	*Uvarovite*	= 3.4

The following table contains the calculated percentage composition of the several pure garnet molecules and the records of analyses of some typical varieties of the mineral:

	SiO_2	Al_2O_3	Fe_2O_3	Cr_2O_3	FeO	MgO	CaO	MnO	TiO_2	Total
I_a	40.01	22.69	.....	.....	.....	.....	37.30	.....	.....	100.00
I_b	42.01	17.76	.....	.....	5.06	.13	35.01	.20	.....	100.17
II_a	44.78	25.40	.....	.....	....	29.82	.....	.....	.....	100.00
II_b	40.92	22.45	5.46	.....	8.11	17.85	5.04	.46	.....	100.39
III_a	36.30	20.75	.....	.....	....	.....	.....	42.95	.....	100.00
III_b	36.34	12.63	4.57	.....	....	.47	1.49	44.20	.....	99.70
IV_a	36.15	20.51	43.34	.....	....	.....	.....	.....	.....	100.00
IV_b	37.61	22.70	33.83	.....	....	3.61	1.44	1.12	.....	100.31
V_a	35.45	.....	31.49	.....	....	.....	33.06	.....	.....	100.00
V_b	35.09	tr.	29.15	.....	2.49	.24	32.80	.36	.....	100.48
V_c	26.36	.....	22.00	.....	....	1.25	30.72	tr.	21.56	101.89
VI_a	38.23	.....	.....	29.27	....	.....	29.27	.....	.....	100.00
VI_b	36.93	5.68	1.96	21.84	....	1.54	31.63	.....	.....	99.58

I_a. Theoretical composition of the grossularite molecule.
I_b. Green and red grossularite from the limestone at Santa Clara, Cal.
II_a. Theoretical composition of the pure pyrope molecule.
II_b. Pyrope from a peridotite in Elliot Co., Ky. Also, H_2O = .10.
III_a. Theoretical composition of spessartite.
III_b. Spessartite from Amelia Court House, Va.
IV_a. Theoretical composition of almandite.
IV_b. Almandite from Salida, Colo.
V_a. Theoretical composition of andradite.
V_b. Andradite from East Rock, New Haven, Conn. Also, H_2O = .35.
V_c. Schorlomite from Magnet Cove, Ark.
VI_a. Theoretical composition of uvarovite.
VI_b. Uvarovite from Bissersk, Urals.

The crystals of garnet are usually simple combinations of $\infty O(110)$ (Fig. 166); $2O2(211)$ and often $3O\frac{3}{2}(321)$ (Figs. 167 and 168), although all the other holohedrons are also occasionally met with. Their cleavage which is indistinct is parallel to $\infty O(110)$.

When examined in polarized light many garnets, especially those occurring in metamorphic rocks, are doubly refracting and, therefore, have not the molecular structure belonging to isometric crystals. This

FIG. 166.—Garnet Crystal. (Natural size.) Form: ∞O (110).

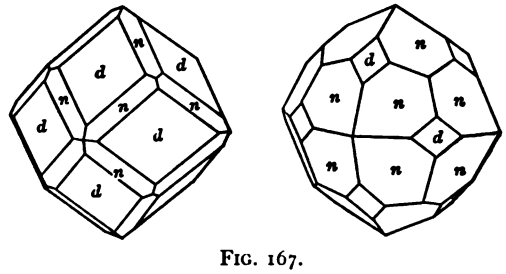


FIG. 167.

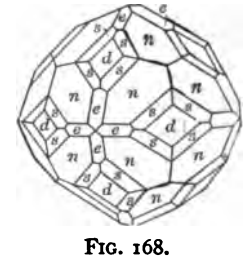


FIG. 168.

FIG. 167.—Garnet Crystals with ∞O, 110 (*d*) and 2O2, 211 (*n*).

FIG. 168.—Garnet Crystal with *d* and *n* as in Fig. 167. Also ∞O2, 210 (*e*) and 3O$\frac{3}{2}$, 231 (*s*).

phenomenon has been explained as due to several causes, the most reasonable explanation ascribing it to strains produced in the crystals upon cooling.

The garnets vary in color according to their composition, the commonest color being reddish brown. Their luster is vitreous, their streak white, hardness 6–7.5, and density 3.4–4.3. They are transparent or translucent. Most varieties are easily fusible to a light brown or black glass, which in the case of the varieties rich in iron is magnetic. Uvarovite, however, is almost infusible. Some garnets are unattacked by acids; others are partially decomposed.

Garnets, when in crystals, are easily distinguished from other similarly crystallizing substances by their color and hardness. Massive garnet may resemble *vesuvianite*, *sphene*, *zircon* or *tourmaline*. It is distinguished from zircon by its easier fusibility and from vesuvianite by its more difficult fusibility; from tourmaline by its higher specific gravity, and from sphene by the reaction from titanium.

Under the influence of the air and moisture garnets may be partially or entirely changed to epidote, muscovite, chlorite, serpentine, and occasionally to other substances.

Grossularite, Essonite, Hessonite, or Cinnamon Garnet occurs principally in crystalline schists and in metamorphosed limestones, where it is associated with other calcium silicates. It is found also in quartz veins. The mineral is white, bright yellow, cinnamon-brown or some pale shade of green or red. The lighter-colored varieties are transparent or nearly so. Those that are colored are used as gems. Much of the *hyacinth* of the jewelers is a red grossularite (see p. 317). Its hardness is about 7 and its density 3.4–3.6. It is fairly easily fusible before the blowpipe. The refractive index of colorless varieties for yellow light is, $n = 1.7438$.

Good crystals of grossularite occur at Phippsburg, Raymond and Rumford, in Maine, and at many other places both in this country and abroad. Bright yellow varieties are reported from Canyon City, Colo.

Pyrope is deep red, sometimes nearly black. Its hardness is a little greater than 7 and its density 3.7. Its refractive index for yellow light is between 1.7412 and 1.7504. The pure magnesium garnet is unknown. All pyropes contain admixtures of iron and calcium molecules. Many pyropes are transparent. Those with a dark red color are used as gems. They occur principally in basic igneous rocks.

The principal occurrence of the gem variety in this country is in Utah, near the Arizona line, about 100 miles west of Ganado, Ariz., where it is found lying loose in wind-blown sand.

Rhodolite is a pale rose-red or purple variety from Macon Co., N. C. It consists of two parts pyrope and one of almandite.

Spessartite is hyacinth or brownish red, with occasionally a tinge of violet. The purest varieties are yellow, but since there is nearly always an admixture of one of the iron molecules, the more usual color is reddish brown. The mineral is usually transparent. Its hardness is 7 or a little greater, and its density 3.77–4.27. Its refractive index for yellow light is 1.8105. In the blowpipe flame it fuses fairly easily to a black, nonmagnetic mass, and with borax gives an amethyst bead. It is found in acid igneous rocks and in various schists.

Its best known occurrences in the United States are in granite, at Haddam, Conn., in pegmatite, at Amelia Court House, Va., and in the lithophyse of rhyolites, near Nathrop, in Colorado.

Almandite is deep red, brownish red or black. It is one of the commonest of all garnets. It furnishes nearly all the material manufactured into abrasives. Transparent varieties are also used as gems. The mineral has a hardness of 7 and over. Its density is 4.1–4.3, and its refractive index, n, for yellow light, is about 1.8100. It is slightly decomposed by HCl. Before the blowpipe it fuses to a dark gray or black magnetic mass. It is found in granites and andesites, and also in various gneisses and schists and in ore veins.

Its best known occurrences in North America are at Yonkers and at various points in the Adirondacks, N. Y., at Avondale, Pa., and on the Stickeen River, in Alaska.

Andradite, or **melanite,** is black, brown, brownish red, green, brownish yellow or topaz-yellow. The purest varieties are topaz-yellow or light green and transparent. The former constitute the gem *topazolite* and the latter, *demantoid*. The black variety, melanite, nearly always contains titanium. It occurs in alkaline igneous rocks, in serpentine, in crystalline schists and in iron ores. The most titaniferous varieties are known as *schorlomite*. The hardness of andradite is about 7 and its density between 3.3 and 4.1. n for yellow light $=1.8566$. It is fusible before the blowpipe to a black magnetic mass.

The mineral is very widely spread. It occurs at Franklin, N. J., in metamorphosed limestone; near Franconia, N. H., in quartz veins, and at many other places. A black titaniferous variety occurs in a metamorphosed limestone in southwestern California and near Magnet Cove, in Arkansas. The variety found at Magnet Cove is schorlomite. It is a black glassy mineral associated with brookite (TiO_2), nepheline (p. 314), and thomsonite (p. 455).

Common garnet is a mixture of the grossularite, almandite and

andradite molecules. It occurs in many metamorphosed igneous rocks and in some slates.

Uvarovite is emerald-green. It is rare, occurring only with chromite in serpentine at Bissersk and Kyschtim in the Urals and in the chromite mines at Texas, Penn., and New Idria, Cal. Its hardness is about 7 and density 3.42. Its refractive index for yellow light is 1.8384. It is infusible before the blowpipe but dissolves in borax, producing a green bead.

Syntheses.—Garnet crystals have been produced by fusing 9 parts of nepheline and 1 part of augite (p. 374). The fusion results in a crystalline mass of nepheline, in which spinel and melanite crystals are embedded.

Occurrence.—The members of the garnet group are widely spread in nature. They occur in schists, slates and other regionally metamorphosed rocks, in granite, rhyolite and other igneous rocks, and as contact products in limestones. They are found also in quartz veins, in pegmatite, and associated with other silicates in ore veins. In some instances they separated from a cooling magma, in others they are the products of pneumatolitic process, and in others they are the results of contact and dynamic metamorphism.

Uses and Production.—The varieties that are transparent are used as gems. Other varieties are crushed and employed as abrasives. The value of the gem material produced in the United States in 1912 was $860. The production for abrasive purposes was 4,182 short tons, valued at $137,800. All of this was produced in the mountain regions of New York, New Hampshire and North Carolina. The rock is crushed and the garnet separated by hand picking, screening, or by jigging. The crushed material is used largely in the manufacture of garnet paper.

NEPHELINE GROUP

The nepheline group of minerals includes three closely related compounds, of which nepheline is the most common. They are all aluminosilicates of the alkalies. *Nepheline* appears to be a solution of SiO_2, or of albite, in isomorphous mixtures of the orthosilicates, $NaAlSiO_4$ and $KAlSiO_4$ in the proportion of 8 molecules of the silicates to one of SiO_2, thus:

$$8(Na \cdot K)AlSiO_4 + SiO_2 = (Na \cdot K)_6((Na \cdot K)AlSiO_3)_2Al_6(SiO_4)_7$$

The other two members of the group are *eucryptite* ($LiAlSiO_4$) and *kaliophilite* ($KAlSiO_4$).

The members of the group crystallize in the hexagonal system and are apparently holohedral, but nepheline is hemihedral and hemimorphic (hexagonal pyramidal class). At temperatures above 1,248° the nepheline molecule crystallizes also in the triclinic system as *carnegieite* (see p. 418).

Nepheline ($(Na \cdot K)_8Al_8Si_9O_{34}$)

Although approximately a potash-soda silicate, nearly all specimens of nepheline contain more or less CaO and nearly all contain small quantities of water. All contain an excess of SiO_2. To avoid the necessity of assuming the existence of this SiO_2 in solution with $(Na \cdot K)AlSiO_4$, it has been suggested that the variable composition of the mineral may be explained by regarding it as a solid solution of $NaAlSi_3O_8$ and $CaAl_2Si_2O_8$ (best known in their triclinic forms as *albite* and *anorthite*) in an isomorphous mixture of the two molecules, $NaAlSiO_4$ and $KAlSiO_4$. The average of five analyses of crystals from Monte Somma, Italy, is shown in I, and the composition of a mass of the mineral from Litchfield, Maine, in II.

	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	H_2O	Total
I.	44.08	33.28	1.57	.19	16.00	4.76	.15	100.03
II.	43.74	34.48	tr	tr	16.62	4.55	.86	100.25

When found in crystals, the mineral is apparently holohedral in form with an axial ratio 1 : .8389. The crystals are nearly always short columnar in habit and usually consist of very simple combinations. The most prominent forms are $\infty P(10\bar{1}0)$, $\infty P2(11\bar{2}0)$, $oP(0001)$, $2P(20\bar{2}1)$, $P(10\bar{1}1)$, $\frac{1}{2}P(10\bar{1}2)$ and $2P2(11\bar{2}1)$ (Fig. 169). Their cleavage is imperfect parallel to $\infty P(10\bar{1}0)$ and $oP(0001)$.

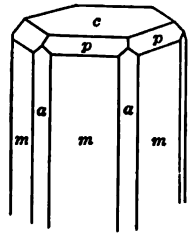


FIG. 169.—Nepheline Crystal with oP, 0001 (*c*); ∞P, $10\bar{1}0$ (*m*); P, $10\bar{1}1$ (*p*) and $\infty P2$, $11\bar{2}0$ (*a*).

Nepheline is glassy, white or gray and transparent, when occurring as implanted crystals. The translucent variety with a glassy luster that occurs in rocks is known as *eleolite*. This variety may be gray, pink, brown, yellowish or greenish. The streak is always white. The fracture of both forms is conchoidal or uneven; hardness, 5–6 and density, 2.6. For yellow light, $\omega = 1.5424$, $\epsilon = 1.5375$.

Before the blowpipe nepheline melts to a white or colorless blebby glass. At 1,248° it passes over into carnegieite which melts at 1,526°. It dissolves in hydrochloric acid with the production of gelatinous silica. Its powder before and after roasting reacts alkaline.

The mineral is distinguished from other silicates by its crystallization, gelatinization with acids, and hardness. The massive varieties are often distinguishable by their greasy luster.

Nepheline alters to various hydrated compounds, especially to the zeolites (p. 445), and to gibbsite, muscovite, cancrinite and sodalite.

Syntheses.—Nepheline has been prepared by fusing together Al_2O_3, SiO_2 and Na_2CO_3, and by the treatment of muscovite by potassium hydroxide.

Occurrence.—The mineral occurs principally as an original constituent of many igneous rocks, both plutonic and volcanic, and also as crystals on walls of cavities in them.

Localities.—Crystals occur near Eberbach, in Baden; in the inclusions within volcanic rocks at Lake Laach, in Rhenish Prussia; in the older lavas of Monte Somma, Naples, Italy; at Capo de Bove, near Rome; in southern Norway; and at various other points in southern Europe. Massive forms are found in coarse-grained rocks near Litchfield, Maine; Red Hill, N. H.; Magnet Cove, Ark.; in the Crazy Mts., Mont., and at other places.

Cancrinite ($H_6(Na_2Ca)_4(NaCO_3)_2Al_8(SiO_4)_9$)

Cancrinite is extremely complex in composition. It is nearly allied to nepheline but contains a notable quantity of CO_2. It corresponds approximately to an hydrated admixture of Na_2CO_3 and $3NaAlSiO_4$, in which some of the Na is replaced by K and Ca. Specimens from Barkevik (I) in Norway, and from Litchfield (II), in Maine, yield the following analyses:

	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	K_2O	CO_2	H_2O	Total
I.	37.01	26.42	....	7.19	18.36	....	7.27	3.12	99.37
II.	36.29	30.12	tr.	4.27	19.56	.18	6.96	2.98	100.36

Cancrinite is hexagonal (dihexagonal bipyramidal class).

Crystals are rare, and those that do exist are very simple, prismatic forms bounded by $\infty P(10\bar{1}0)$, $\infty P2(11\bar{2}0)$, $oP(0001)$ and $P(10\bar{1}1)$. Their axial ratio is 1 : .4410.

The mineral is usually found without crystal planes. It is colorless, white or some light shade, such as rose, bluish gray or yellow. Its streak is white, its luster glassy, greasy or pearly and it is translucent. Its cleavage is perfect parallel to $\infty P(10\bar{1}0)$ and less perfect parallel to $\infty P2'(11\bar{2}0)$. Its break is uneven; hardness 5 and density 2.45. For red light: $\omega = 1.5244$, $\epsilon = 1.4955$.

Before the blowpipe the mineral loses its color, swells and fuses to a colorless blebby glass. In the closed glass tube it loses CO_2 and water, and becomes opaque. After roasting it is easily attacked by weak acids with effervescence and the production of gelatinous silica. When boiled with water Na_2CO_3 is extracted in sufficient quantity to give an alkaline reaction.

Cancrinite is easily distinguished by its effervescence with acids and the production of gelatinous silica.

Synthesis.—Small colorless, hexagonal crystals with a composition corresponding to that of cancrinite, have been made by treating muscovite with a solution of NaOH and Na_2CO_3 at 500°.

Occurrence.—The mineral occurs principally as an associate of nepheline in certain coarse-grained igneous rocks. In some cases it appears to be an original rock constituent and in others an alteration product of nepheline. It sometimes alters to natrolite (see p. 454), forming pseudomorphs.

Localities.—Cancrinite is found in rocks at Ditro, Hungary; at Barkevik and other localities in southern Norway, where it occurs in pegmatite dikes; in the parish of Kuolajärvi, in Finland, and in nepheline syenite at Litchfield in Maine.

ZIRCON GROUP

The orthosilicates of zirconium, *zircon*, and of thorium, *thorite*, constitute a group, the members of which possess forms that are almost identical with those of rutile, cassiterite and xenotime. Indeed, parallel growths of zircon and xenotime are not uncommon. Formerly zircon was grouped with the two oxides.

Zircon and thorite are tetragonal (ditetragonal bipyramidal class), with approximately the same axial ratios and the same pyramidal angles. The two minerals are completely isomorphous.

Zircon	$ZrSiO_4$	$a : c = .6391$	$111 \wedge 1\bar{1}1 = 56° 37'$,
Thorite	$ThSiO_4$	$= .6402$	$= 56° 40'$.

Zircon is fairly common. Thorite is rare.

Zircon ($ZrSiO_4$)

Zircon, like rutile, is a fairly common compound of a comparatively rare metal. It is practically the only ore of the metal zirconium. It is found mainly in crystals and as gravel.

Although some specimens of zircon contain a large number of elements, others consist only of zirconium, silicon and oxygen in proportions that correspond to the formula $ZrSiO_4$, which demands 67.2 per cent ZrO and 32.8 per cent SiO_2.

Its axial ratio is $a : c = 1 : .6391$. Its crystals are usually simple combinations of ∞P(110) and P(111), with the addition of ∞P∞ (100)

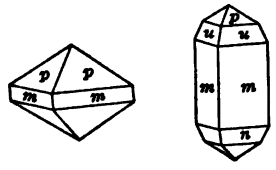


FIG. 170.

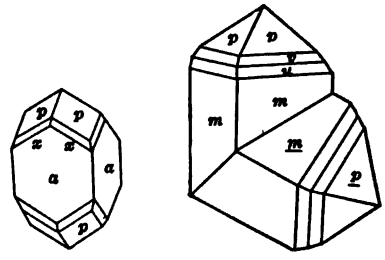


FIG. 171.

FIG. 170.—Zircon Crystals with ∞P, 110 (*m*); ∞P∞, 100 (*a*); 3P, 331 (*u*), P, 111 (*p*) and 3P3, 311 (*x*).
FIG. 171.—Zircon Twinned about P∞ (101). *v* = 2P (221).

and often 3P3(311) (Fig. 170). Elbow twins, like those of rutile and cassiterite, are known (Fig. 171).

The cleavage of zircon is very indistinct. Its fracture is conchoidal. Its hardness is 7.5 and density about 4.7. The mineral varies in tint from colorless, through yellowish brown to reddish brown. Its streak is uncolored and luster adamantine. Most varieties are opaque, but transparent varieties are not uncommon. The orange, brown and reddish transparent kinds constitute the gem known as ***hyacinth***. The refractive indices for yellow light are: $\omega = 1.9302$, $\epsilon = 1.9832$.

Zircon is infusible, though colored varieties often lose their color when strongly heated. In the borax and other beads the mineral gives no preceptible reactions. In fine powder it is decomposed by concentrated sulphuric acid. When fused with sodium carbonate on platinum it is likewise decomposed, and the solution formed by dissolving the fused mixture in dilute hydrochloric acid turns turmeric paper orange. This is a characteristic test for the zirconium salts.

The mineral is easily recognized by its hardness, its resistance toward reagents and its crystallization.

Syntheses.—Small crystals of zircon are obtained by heating for several hours in a steam-tight platinum crucible a mixture of gelatinous silica and gelatinous zirconium hydroxide. Crystals have also been made by heating for a month a mixture of ZnO_2 and SiO_2 with 6 times their weight of lithium bimolybdate.

Occurrence and Origin.—Zircon is widely spread in tiny crystals as a primary constituent in many rocks, and in large crystals in a few, notably in limestone and a granite-like rock known as nepheline syenite. In limestone it is a product of contact action. It occurs also in sands, more particularly in those of gold regions, and abundantly in a sandstone near Ashland, Va.

Localities.—The principal occurrences of the mineral are Ceylon, the home of the gem hyacinth; the gold sands of Australia; Arendal, Hakedal and other places in Norway; Litchfield and other points in Maine; Diana, in Lewis Co., and a large number of other places in New York; at Reading, Penn.; Henderson and other Counties, in North Carolina and Templeton, Ottawa Co., Quebec.

Uses.—Zircon is the principal source of the zirconium oxide employed in the manufacture of gauze used in incandescent gas lights and in the manufacture of cylinders for use in procuring a light from the oxyhydrogen jet. The mineral has been mined for these purposes in Henderson Co., North Carolina.

Transparent orange-colored zircons are sometimes used as gems since they possess a high index of refraction and consequently have a great deal of "fire." These are the true hyacinth. The mineral often called by this name among the jewelers is a yellowish brown garnet.

Production.—A small quantity of zircon is usually obtained from Henderson Co., N. C., but it rarely amounts to more than a few hundred pounds. The mineral occurs in a pegmatite and the soil overlying its outcrop. It is obtained by crushing the rock and hand picking. Usually there is a little also separated from the sands in North Carolina and South Carolina that are washed for monazite. A pegmatite dike, rich in zircon, is also being prospected in the Wichita Mountains, Okla., but no mining has yet been attempted.

Thorite ($ThSiO_4$)

Thorite occurs in simple crystals bounded by $\infty P(110)$ and $P(111)$ (Fig. 172), and in masses. The mineral is always more or less hydrated, but this is believed to be due to partial weathering. It is black or orange-yellow (*orangeite*), has a hardness of 5 and a specific gravity of 4.5–5 for black varieties and 5.2–5.4 for orange varieties. Its streak is brown or light orange. Hydrated specimens are soluble in hydrochloric acid with the production of gelatinous silica. The mineral occurs as a constituent of the igneous rock, augite-syenite, at several points in the neighborhood of the Langesundfjord, Norway.

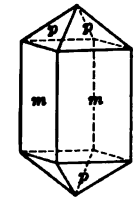


FIG. 172.—Thorite Crystal with ∞P, 110 (*m*) and P, 111 (*p*).

BASIC ORTHOSILICATES

ANDALUSITE GROUP

Three compounds with the empirical formula Al_2SiO_5 exist as minerals, *kyanite*, or *disthene*, *andalusite* and *sillimanite*. The first named is less stable with reference to chemical agents than the other two, but at high temperatures both kyanite and andalusite are transformed into sillimanite. Kyanite is regarded as a metasilicate $(AlO)_2SiO_3$. The other two are thought to be orthosilicates $(Al(AlO)SiO_4)$. The latter are orthorhombic and both possess nearly equal prismatic angles. They differ markedly, however, in their optical and other physical properties and, therefore, are different substances. Kyanite is triclinic. For this reason and because of its different composition it is not regarded as a member of the andalusite group. A fourth mineral, *topaz*, differs from andalusite in containing fluorine. Often this element is present in sufficient quantity to replace all of the oxygen in the radical (AlO). In other specimens the place of some of the fluorine is taken by hydroxyl (OH). The general formula that represents these variations is $Al(Al(F \cdot OH)_2)SiO_4$. The mineral crystallizes in forms that are very like those of andalusite, and if corresponding pyramids are selected as groundforms their axial ratios are nearly alike. Unfortunately, however, different pyramids have been accepted as groundforms, and therefore the similarity of the crystallization of the two minerals has been somewhat obscured. *Danburite*, another mineral that crystallizes in the orthorhombic system with a habit like that of topaz is often also placed in this group, although it is a borosilicate, thus $CaB_2(SiO_4)_2$.

If $4P\breve{2}(241)$ be taken as the groundform of andalusite, $3P(331)$ as that of topaz and $3P(331)$ as that of danburite, the corresponding axial ratios would be:

Andalusite	$a : b : c =$	$.5069 : 1 : 1.4246$
Topaz	$=$	$.5281 : 1 : 1.4313$
Danburite	$=$	$.5445 : 1 : 1.4402$

These, however, are not the accepted ratios, since other and more prominent pyramids have been selected as the groundforms.

Andalusite and Sillimanite ($Al(AlO)SiO_4$)

Andalusite and sillimanite have the same empirical chemical composition and crystallize with the same symmetry, which is orthorhombic holohedral (rhombic bipyramidal class), but they have different physical properties and different crystal habits, and hence are regarded as different minerals. The theoretical composition of both is:

$$SiO_2 = 37.02; \quad Al_2O_3 = 62.98. \quad \text{Total} = 100.00.$$

Nearly all specimens when analyzed show the presence of small quantities of Fe, Mg, and Ca, but otherwise they correspond very closely to the theoretical composition.

Both minerals are characteristic of metamorphosed rocks, but andalusite occurs principally in those that have been metamorphosed by contact with igneous intrusives, while sillimanite is especially characteristic of crystalline schists and, in general, of rocks that were dynamically metamorphosed. It also occurs with olivine as inclusions in basalt lavas. Sillimanite is more stable at high temperatures than andalusite. When in contact rocks it is found nearer the intrusive than andalusite.

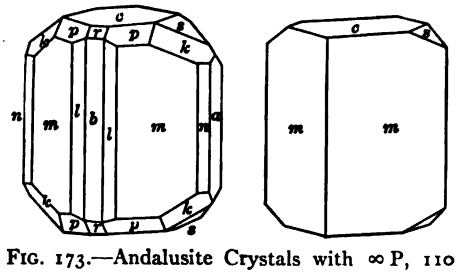


FIG. 173.—Andalusite Crystals with ∞P, 110 (m); oP, 001 (c); $P\breve{\infty}$, 011 (s); $\infty P\bar{\infty}$, 100 (b); $\infty P\breve{\infty}$, 010 (a); $\infty P\bar{2}$, 210 (l); $\infty P\breve{2}$, 120 (n); $P\bar{\infty}$, 101 (r); P, 111 (p) and $2P\breve{2}$, 121 (k).

Andalusite.—The accepted axial ratio of andalusite is $.9861 : 1 : .7024$. Its crystals are columnar in habit and are usually simple combinations of $\infty P\bar{\infty}$ (100), $\infty P\breve{\infty}$ (010), oP(001), ∞P(110), $\infty P\bar{2}$(210), $\infty P\breve{2}$(120) $P\bar{\infty}$ (101), $P\breve{\infty}$ (011) with sometimes P (111) and $2P\breve{2}$(121) (Fig. 173). The angle $110 \wedge 1\bar{1}0 = 89° 12'$.

The mineral, when fresh, is greenish or reddish and transparent. Usually, however, it is more or less altered, and is opaque, or, at most, translucent, and gray, pink or violet. Its cleavage is good parallel to $\infty P(110)$ and its fracture uneven. Its hardness is 7 or a little less and its density 3.1–3.2. In some specimens pleochroism is marked, their colors being olive-green for the ray vibrating parallel to *a*, oil-green for that vibrating parallel to *b* and dark red for that vibrating parallel to *c*. For yellow light the indices of refraction are: $\alpha = 1.6326$, $\beta = 1.6390$, $\gamma = 1.6440$.

Before the blowpipe the mineral gradually changes to sillimanite and is infusible. When moistened with cobalt nitrate and roasted it becomes blue. It is insoluble in acids.

The mineral is distinguished by its nearly square cross-section, its hardness, its infusibility, and the reaction for Al, and by its manner of occurrence in schists and metamorphosed slates.

Some specimens contain as inclusions large quantities of a dark gray or black material, which may be carbonaceous, arranged in such a way as to give a cross-like figure in cross-sections of crystals. Because of the shape of the figure exhibited by these crystals, this variety was early called *chiastolite*, and was valued as a sacred charm.

Andalusite alters readily to kaolin (p. 404), muscovite (p. 355), and sillimanite. It has not been produced artificially.

Occurrence.—Andalusite is found principally in clay slates and schists that have been metamorphosed by contact with igneous masses, and to a less extent in gneisses.

Localities.—Its principal occurrences are in Andalusia, Spain; at Bräunsdorf, Saxony; at Gefrees, in the Fichtelgebirge; in Minas Geraes, Brazil, and in the United States at Standish, Maine; Westford, Mass., and Litchfield, Conn. Chiastolite occurs at Lancaster and Sterling, Mass.

Use.—The only use to which andalusite has been put is as a semi-precious stone, and for this purpose only the chiastolite variety is of any value.

Sillimanite, or **fibrolite,** occurs principally in acicular or fibrous aggregates, on the individuals of which only the prismatic forms $\infty P(110)$ and $\infty P\frac{3}{2}(230)$ and the macropinacoid $\infty P\bar{\infty}(100)$ can be detected. End faces are not sufficiently developed to warrant the determination of an axial ratio. The relative values of the *a* and *b* axes are .687 : 1. The angle $110 \wedge 1\bar{1}0 = 69°$.

While most of the fibers correspond in composition very closely to the

theoretical value demanded by the formula $Al(AlO)SiO_4$, many contain small quantities of Fe_2O_3, MgO and H_2O.

The mineral is yellowish gray, greenish gray, olive-green or brownish. It has a glassy or greasy luster and when pure is transparent. Most specimens, however, are translucent, and many of the colored varieties show a pleochroism in brown or reddish tints. Its cleavage is perfect parallel to $\infty P \bar{\infty}$ (100). Its needles have an uneven fracture transversely to their long directions. Their streak is colorless, hardness 6–7 and density 3.24. The indices of refraction for the lighter colored varieties are: $\alpha = 1.6603$, $\beta = 1.6612$, $\gamma = 1.6818$ for yellow light.

Sillimanite reacts similarly to andalusite toward reagents and before the blowpipe. It is distinguished from other minerals by its habit and manner of occurrence.

This mineral is much more resistant to weathering than is andalusite. It is, however, occasionally found altered to kaolin. On the other hand, it is known also in pseudomorphs after corundum.

Synthesis.—It has been produced by cooling fused silicate solutions rich in aluminium.

Occurrence.—Sillimanite is very widely spread in schistose rocks, especially those that have been formed from sediments. It is essentially a product of dynamic metamorphism, but is formed also by contact metamorphism, in which case it is found near the intrusive, where the temperature was high.

Localities.—Its principal occurrences in North America are in quartz veins cutting gneisses at Chester, Conn., at many points in Delaware Co., Penn., and at the Culsagee Mine, Macon Co., N. C. At the latter place and at Media in Penn., a fibrous variety occurs in such large masses as to constitute a schist—known as *fibrolite schist.*

Topaz ($Al(Al(F \cdot OH)_2)SiO_4$)

Topaz is a common constituent of many ore veins and is often present on the walls of cracks and cavities in volcanic rocks. It occurs massive and also in distinct and handsome crystals.

The mineral has a varying composition, which is explained in part by the fact that it is a mixture of the two molecules $Al(AlF_2)SiO_4$ and $Al(Al(OH)_2)SiO_4$. The theoretical composition of the fluorine molecule is: $SiO_2 = 32.6$, $Al_2O_3 = 55.4$; $F = 20.7 = 108.7$; deduct $(O = 2F)8.7 = 100.00$. A specimen from Florissant, Colo., gave:

$$SiO_2 = 33.15;\ Al_2O_3 = 57.01;\ F = 16.04 = 106.20 - 6.75(O = F) = 99.45.$$

Crystals of topaz appear to be orthorhombic (rhombic bipyramidal class), but the fact that they are pyroelectric and that they frequently exhibit optical phenomena that are not in accord with the symmetry of orthorhombic holohedrons suggests that they may possess a lower grade of symmetry. On the assumption that the mineral crystallizes with the symmetry of orthorhombic holohedrons the axial ratio of fluorine varieties is .5281 : 1 : .4771.[1] With the increasing presence of OH, however, the relative length of *a* increases and that of *c* diminishes. The angle $110 \wedge 1\bar{1}0 = 55^\circ\ 43'$.

The crystals are usually prismatic in habit with ∞P(110) and ∞P$\breve{2}$(120) predominating. They are notable for the number of forms

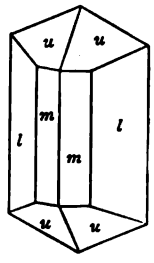
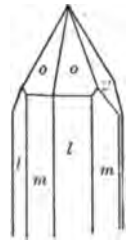


FIG. 174.



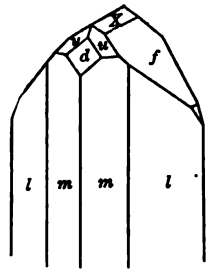


FIG. 175.

FIG. 174.—Topaz Crystals with ∞P, 110 (*m*); ∞P$\breve{2}$, 120 (*l*); P, 111 (*u*); 2P, 221 (*o*) 4P$\breve{\infty}$, 041 (*y*) and ∞P$\breve{\infty}$, 010 (*b*).

FIG. 175.—Topaz Crystal with *m*, *l*, *n* and *y* as in Fig. 174. Also 2P$\breve{\infty}$, 021 (*f*); $\frac{4}{3}$P$\breve{\infty}$, 043 (*X*) and 2P$\bar{\infty}$, 201 (*d*).

that have been observed on them, especially in the prismatic zone and among the brachypyramids. The number of the latter that have already been identified is about 45.

The three types of crystals that are most common are shown in Figs. 174, 175 and 176. Their most prominent forms are ∞P(110), ∞P$\breve{2}$(120), P$\breve{\infty}$(011), P(111), $\frac{2}{3}$P(223), 4P$\bar{\infty}$(041), ∞P$\breve{3}$(130) and oP(001). Often planes are absent from one end of the vertical axis, but since the etch figures on the prismatic planes do not indicate hemimorphism, the absence of the lacking planes is explained as being due to unequal growth. The planes of the prismatic zone are usually striated.

The mineral is colorless, honey yellow, yellowish red, rose and rarely bluish. When exposed to the sunlight the colored varieties fade, and

[1] The more commonly accepted axial ratio is $a : b : c = .5285 : 1 : .9539$, the form 2P(221) being taken as the groundform.

when intensely heated some honey-yellow crystals turn rose-red. Its cleavage is perfect parallel to oP(001) and imperfect parallel to P $\breve{\infty}$ (011) and P $\bar{\infty}$ (101). The hardness of the mineral is 8 and its density 3.5–3.6. Its refractive indices for yellow light are: $\alpha = 1.6072$, $\beta = 1.6104$, $\gamma = 1.6176$ for a variety containing very little OH, and $\alpha = 1.6294$, $\beta = 1.6308$, $\gamma = 1.6375$ for a variety rich in hydroxyl. The indices of refraction being high, the mineral when cut exhibits much brilliancy—a feature which, together with its hardness, gives it much of its value as a gem.

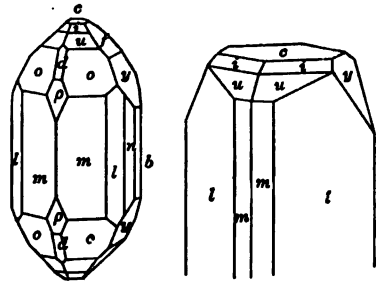


FIG. 176.—Topaz Crystal with *m*, *l*, *y*, *f*, *d*, *O* and *u* as in Figs. 174 and 175. Also $\frac{3}{2}$P, 223 (*i*); oP, 001 (*c*) and 4P $\bar{\infty}$, 401 (*ρ*).

Topaz is infusible before the blowpipe and is insoluble in acids. At a high temperature it loses its fluorine as silicon and aluminium fluorides. The mineral also exhibits pyroelectrical properties, but these are apparently distributed without regularity in different crystals. Many crystals contain inclusions of fluids containing bubbles, and sometimes of two immiscible fluids the nature of which has not yet been determined. It has been thought that the principal fluid present is liquid carbon-dioxide or some hydrocarbon.

The mineral is distinguished from yellow *quartz* by its crystallization, its greater hardness and its easy cleavage.

Topaz is frequently found coated with a micaceous alteration product which may be steatite (p. 401), muscovite (p. 355) or kaolin (p. 404).

Synthesis.—Crystals have been made by the action of hydrofluosilicic acid (H_2SiF_6) upon a mixture of silica and alumina in the presence of water at a temperature of about 500°.

Occurrence.—The mineral occurs principally in pegmatites, especially those containing cassiterite, in gneisses, and in acid volcanic rocks. In all cases it is probably the result of the escape of fluorine-bearing gases from cooling igneous magmas.

Localities.—Topaz is found in handsome crystals at Schneckenstein in Saxony, in a breccia made up of fragments of a tourmaline-quartz rock cemented by topaz. It occurs also in the pegmatites of the tin mines in Ehrenfriedersdorf, Marienberg and other places in Saxony, Bohemia, England, etc.; on the walls of cavities in a coarse granite in Jekaterinburg and the Ilmengebirge, Russia; in veins of kaolin cutting a talc schist in Minas Geraes in Brazil; and in the cassiterite-bearing

sands at San Luis Potosi, Durango and other points in Mexico. In the United States it occurs on the walls of cavities in acid volcanic rocks, at Nathrop, Colo., in the Thomas Range, Utah, and other places. It occurs also in veins with muscovite, fluorite, diaspore and other minerals at Stoneham, Maine, and Trumbull, Conn.

Uses and Production.—Topaz is used as a gem. About 36 lb., valued at $2,675, was produced in the United States in 1911. In the following year the production was valued at only $375.

Danburite ($CaB_2(SiO_4)_2$)

Danburite, which is a comparatively rare mineral, is a calcium borosilicate with the following theoretical composition: $SiO_2 = 48.84$; $B_2O_3 = 28.39$ and $CaO = 22.77$. Usually, however, there are present in it small quantities of Al_2O_3, Fe_2O_3, Mn_2O_3 and H_2O. Thus, crystals from Russell, New York, contain:

SiO_2	B_2O_3	Al_2O_3, etc.	H_2O	CaO	Total
49.70	25.80	1.02	.20	23.26	99.98

The mineral crystallizes in the orthorhombic system (rhombic bipyramidal class), with an axial ratio .5445 : 1 : .4801. Its crystals are usually prismatic in habit. They contain a great number of forms, of which $\infty P\bar{\infty}$ (100), $\infty P\breve{\infty}$ (010), $\infty P\breve{2}$(120), $\infty P\breve{4}$(140), and ∞P(110) among the prisms, $2P\breve{4}$(142), $2P\breve{2}$(121) among the pyramids and oP(001) are the most prominent (Fig. 177). The angle $110 \wedge 1\bar{1}0 = 57° 8'$.

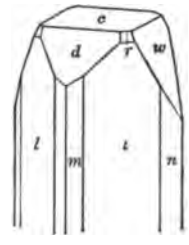


FIG. 177.—Danburite Crystal with ∞P, 110 (*m*); $\infty P\breve{2}$, 120 (*l*); $P\bar{\infty}$, 101 (*d*); $2P\breve{2}$, 121 (*r*) and $4P\breve{\infty}$, 041 (*w*).

When fresh and pure the mineral is transparent, colorless or light yellow, but when more or less impure is pink, honey-yellow or dark brown. Its streak is white, and luster vitreous. Its cleavage is imperfect parallel to oP(001) and its fracture uneven or conchoidal. Its hardness is about 7 and density 2.95–3.02. Its refractive indices for yellow light are: $\alpha = 1.6317$, $\beta = 1.6337$, $\gamma = 1.6383$.

Before the blowpipe the mineral fuses to a colorless glass and colors the flame green. It is only slightly attacked by hydrochloric acid, but after roasting is decomposed with the formation of gelatinous silica. It phosphoresces on heating, glowing with a red light.

Origin.—Danburite is probably always a product of pneumatolytic

action, as it is found in quartz and pegmatite veins in the vicinity of igneous rocks and on the walls of hollows within them.

Localities.—Its principal occurrences in this country are at Danbury, Conn., where it is in a pegmatite, and at Russell, N. Y., on the walls of rocks and hollows in a granitic rock. Its principal foreign occurrence is at Piz Valatscha, in Switzerland.

EPIDOTE GROUP ($Ca_2R'''_3(OH)(SiO_4)_3$)

The epidote group comprises six substances, of which two are dimorphs with the composition $Ca_2Al_3(OH)(SiO_4)_3 = Ca_2Al_2(AlOH)(SiO_4)_3$. One of these, known as *zoisite*, crystallizes in the orthorhombic system, and the other, known as *clinozoisite*, in the monoclinic system. The other four are isomorphous with clinozoisite. These are *hancockite*, *epidote*, *piedmontite* and *allanite*. The composition and comparative axial ratios of the four commoner isomorphs are as follows (assuming $\frac{1}{2}P(\bar{1}12)$ as the groundform of clinozoisite):

Clinozoisite	$Ca_2Al_3(OH)(SiO_4)_3$	1.4457 : 1 : 1.8057
Epidote	$Ca_2(Al \cdot Fe)_3(OH)(SiO_4)_3$	1.5807 : 1 : 1.8057, $\beta = 64° 36'$
Piedmontite	$Ca_2(Al \cdot Mn)_3(OH)(SiO_4)_3$	1.6100 : 1 : 1.8326, $\beta = 64° 39'$
Allanite	$Ca_2(Al \cdot Ce \cdot Fe)_3(OH)(SiO_4)_3$	1.5509 : 1 : 1.7691, $\beta = 64° 59'$

Clinozoisite is rare, though its molecule occurs abundantly in isomorphous mixtures with the corresponding iron molecule in epidote.

Zoisite ($Ca_2Al_3(OH)(SiO_4)_3$)

Zoisite is a calcium, aluminium orthosilicate containing only a small quantity of the corresponding iron molecule. The theoretical composition of the pure Ca molecule is:

$SiO = 39.52$; $Al_2O_3 = 33.92$; $CaO = 24.59$; $H_2O = 1.97$. Total = 100.00.

Colored varieties contain a little iron or manganese. Green crystals (I), from Ducktown, Tenn., and red crystals (*thulite*) (II), from Kleppan, in Norway, analyze as follows:

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	Mn_2O_3	Na_2O	H_2O	Total
I.	39.61	32.89	.91	.71	24.50	.14	....	....	2.12	100.88
II.	42.81	31.14	2.29	...	18.73	...	1.63	1.89	.64	99.13

Zoisite crystallizes in the orthorhombic system (orthorhombic bipyramidal class), with the axial ratio .6196 : 1 : .3429. Its crystals are

usually simple and without end faces. The most frequent forms are $\infty P(110)$, $\infty P\breve{4}(140)$, $\infty P\breve{\infty}(010)$. $P(111)$, $2P\breve{\infty}(021)$ and $4P\breve{\infty}(041)$ are the commonest terminations (Fig. 178). The crystals are all prismatic and are striated longitudinally. Their cleavage is perfect parallel to $\infty P\breve{\infty}(010)$. The angle $110 \wedge 1\bar{1}0 = 63° 34'$.

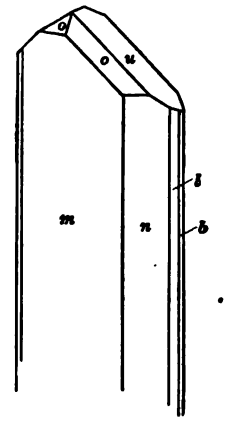


FIG. 178.—Zoisite Crystal with ∞P, 110 (*m*); $\infty P\breve{\infty}$; 010 (*b*); $\infty P\breve{4}$, 140 (*l*), $2P\breve{\infty}$, 021 (*u*) and P, 111 (*o*).

The mineral is ash-gray, yellowish gray, greenish white, green or red in color and has a white streak. The rose-red variety, containing manganese, is known as *thulite*. Very pure fresh zoisite is transparent, but the ordinary forms of the mineral are translucent. Its luster is glassy, except on the cleavage surface, where it is sometimes pearly. Its fracture is uneven. Its hardness is 6 and density about 3.3. In specimens from Ducktown, Tenn., $\alpha = 1.7002$, $\beta = 1.7025$, $\gamma = 1.7058$ for yellow light. A notable fact in connection with this mineral is that with increase of the molecule $Ca_2Fe_3(OH)(SiO_4)_3$ in the mixture the plane of its optical axes tends to change from $oP(010)$ to $\infty P\breve{\infty}(001)$.

Zoisite fuses to a clear glass before the blowpipe and gives off water, which causes a bubbling on the edges of the heated fragments. It is only slightly affected by acids, but after heating it is decomposed by hydrochloric acid with the production of gelatinous silica.

Occurrence.—The mineral occurs as a constituent of crystalline schists, especially those rich in hornblende, or of quartz veins traversing them. It is also a component of the alteration product known as *saussurite* which results from the decomposition of the plagioclase (p. 418) in certain basic, augitic rocks known as gabbros. It is thus a product of metamorphism.

Localities.—Good crystals of zoisite are found near Pregratten in Tyrol; at Kleppan (thulite), Parish Souland, Norway, and in the ore veins at the copper mines of Ducktown, Tenn., where it is associated with chalcopyrite, pyrite and quartz.

Epidote ($Ca_2(Al \cdot Fe)_3(OH)(SiO_4)_3$)

Epidote, or pistazite, differs from the monoclinic dimorph of zoisite (clinozoisite) in containing an admixture of the corresponding iron silicate which is unknown as an independent mineral.

Since it consists of a mixture of an aluminium and an iron compound its composition necessarily varies. The four lines of figures below give the calculated composition of mixtures containing 15 per cent, 21 per cent, 30 per cent and 40 per cent of the iron molecule.

Per cent	SiO_2	Al_2O_3	Fe_2O_3	CaO	H_2O	Total
15.....	38.60	28.80	6.65	24.02	1.93	100.00
21.....	38.23	26.76	9.32	23.78	1.91	100.00
30.....	37.67	23.71	13.31	23.43	1.88	100.00
40.....	37.04	20.32	17.75	23.04	1.85	100.00

Most specimens contain small quantities of Mg, Fe, Mn, Na or K.

Epidote is isomorphous with clinozoisite, crystallizing in the mono-

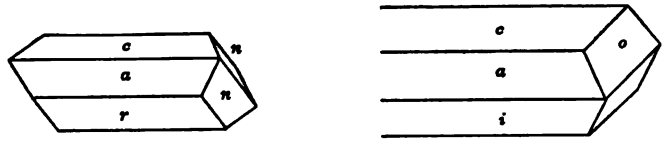


FIG. 179.—Epidote Crystals with $\infty P\bar{\infty}$, 100 (*a*); oP, 001 (*c*); $P\bar{\infty}$, $10\bar{1}$ (*r*); $\frac{1}{2}P\bar{\infty}$, $10\bar{2}$ (*i*); P, $11\bar{1}$ (*n*) and $P\breve{\infty}$, 011 (*o*).

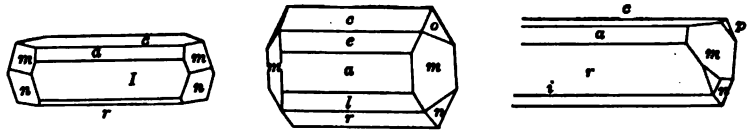


FIG. 180.—Epidote Crystals with *a*, *c*, *r*, *i*, *n* and *o* as in Fig. 179. Also ∞P, 110 (*m*); $2P\bar{\infty}$, $20\bar{1}$ (*l*); $-P\bar{\infty}$, 101 (*e*); $-3P\frac{3}{2}$, 231 (*p*) and $\frac{1}{2}P\bar{2}$, $\bar{4}23$ (*t*).

clinic system (monoclinic prismatic class), with the axial ratio 1.5787 : 1 : 1.8036. $\beta = 64° 36'$. The mineral is remarkable for its handsome crystals, many of which are extremely rich in forms. The crystals are usually columnar in consequence of their elongation parallel to the *b* axis. The most prominent forms are $\infty P\bar{\infty}$ (100), oP(001), $\frac{1}{2}P\bar{\infty}$ ($20\bar{1}$). $P\bar{\infty}$ ($10\bar{1}$), P($11\bar{1}$), ∞P(110) and $P\breve{\infty}$ (011) (Fig. 179 and 180). In addition to these, over 300 other forms have been identified. Twinning is common, with $\infty P\bar{\infty}$ (100) the twinning plane. The angle $110 \wedge 1\bar{1}0 = 109° 56'$.

Epidote is yellowish green, pistachio green, dark green, brown or, rarely, red. It is transparent or translucent and strongly pleochroic. In green varieties the ray vibrating parallel to the *b* axis is brown, that vibrating nearly parallel to *c*, yellow, and that vibrating perpendicular to

the plane of these two is green. Its luster is glassy and its streak gray. Its cleavage is very perfect parallel to oP(001). Its hardness is 6.5 and density 3.3 to 3.5. The refractive indices for yellow light in a crystal from Zillerthal are: $\alpha=1.7238$, $\beta=1.7291$, $\gamma=1.7343$. They increase with the proportion of the iron molecule present, being 1.7336, 1.7593 and 1.7710 in a specimen containing 27 per cent of the iron epidote.

The varieties that have been given distinct names are:

Bucklandite, a greenish black variety in crystals that are not elongated;

Withamite, a bright red variety containing a little MnO.

Fragments of the mineral when heated before the blowpipe yield water and fuse to a dark brown or black mass that is often magnetic. With increase in iron fusion becomes more easy. Before fusion epidote is practically insoluble in acid. After heating HCl decomposes it with the separation of gelatinous silica.

The ordinary forms of the mineral are characterized by their yellowish green color, ready fusibility and crystallization.

Occurrence and Origin.—Epidote occurs in massive veins cutting crystalline schists and igneous rocks, as isolated crystals and druses on the walls of fissures through almost any rock and in any cavities that may be in them, and as the principal constituent of the rock known as epidosite. It is a common alteration product of the feldspars (p. 408), pyroxenes (p. 364), garnet, and other calcium and iron-bearing minerals. Pseudomorphs of epidote after these minerals are well known. The mineral is a weathering product, but is more commonly a product of contact and regional metamorphism.

It has not been produced artificially.

Localities.—Epidote crystals are so widely spread that only a few of the important localities in which they have been found can be mentioned here. Particularly fine crystals occur in the Sulzbachthal, Salzburg, Austria; in the Zillerthal, in Tyrol; near Zermatt, in Switzerland; in the Alathal, Traversella, Italy; at Arendal, Norway; in Japan, at Prince of Wales Island, Alaska, and at many other points in North America.

Piedmontite ($Ca_2(Al \cdot Mn)_3(OH)(SiO_4)_3$)

Piedmontite is the manganese epidote, differing from the ordinary epidote in possessing manganese in place of iron. Usually, however, the iron and the manganese molecules are both present. Typical analyses of crystals from St. Marcel, in Piedmont, Italy (I), Otakisan, Japan (II), and Pine Mt., near Monterey, Md. (III), follow:

	SiO_2	Al_2O_3	Mn_2O_3	MnO	Fe_2O_3	MgO	CaO	H_2O	Total
I.	35.68	18.93	14.27	3.22	1.34	...	24.32	2.24	100.00
II.	36.16	22.52	6.43*		9.33	.40	22.05	.3.20	100.53*
III.	47.37	18.55	6.85	1.92	4.02	.25	15.82	2.08	100.05*

* II. contains also .44 per cent Na_2O. The Mn_2O_3 contained also MnO.

III. contains also 2.03 per cent of the oxides of rare earths, .14 per cent PbO, .11 per cent CuO, .23 per cent Na.O and .68 per cent K_2O. The specimen contained also a little admixed quartz, which was determined with the SiO_2.

The axial ratio of piedmontite is 1.6100 : 1 : 1.8326. $\beta = 64° 39'$. Its crystals are similar in habit to those of epidote, but they are much simpler. The most prominent forms are $\infty P\bar{\infty}$ (100), oP(001), P($\bar{1}$11), $\frac{1}{2}P\bar{\infty}$ ($\bar{1}$02), $\infty P\bar{\infty}$ (010) and ∞P(110). Twins are fairly common, with $\infty P\bar{\infty}$ (100) the twinning plane.

The mineral is rose-red, brownish red or reddish black. It is transparent or translucent and strongly pleochroic in yellow and red tints and has a glassy luster and pink streak. It is brittle, and has a good cleavage parallel to oP(001). Its hardness is 6 and density 3.40. Its refractive indices are the same as those of epidote.

Before the blowpipe piedmontite melts to a blebby black glass and gives the manganese reaction in the borax bead. It is unattacked by acids until after heating, when it decomposes in HCl with the separation of gelatinous silica.

It is characterized by its color and hardness and by its manganese reaction.

Occurrence and Origin.—Piedmontite occurs as an essential constituent of certain schistose rocks that are known as piedmontite schists. It occurs also in veins and in certain volcanic rocks, where it is probably an alteration product of feldspar. Its methods of origin are the same as those of epidote.

Localities.—Good crystals are found in the manganese ore veins at St. Marcel, Piedmont; on ilmenite in crystalline schists on the Isle of Groix, off the south coast of Brittany; and at a number of points on the Island of Shikoku, Japan, in crystalline schists and in ore veins. In the United States it is so abundant in the acid volcanic rocks of South Mountain, Penn., as to give them a rose-red color.

Allanite ($Ca_2(Al \cdot Ce \cdot Fe)_3(OH)(SiO_4)_3$)

Allanite is a comparatively rare epidote in which there are present notable quantities of Ce, Y, La, Di, Er and occasionally other of the rarer elements. Since cerium is present in the largest quantity the

formula of the mineral is usually written as above, with the understanding that a portion of the cerium may be replaced by yttrium and the other elements. Some idea of the complex character of the mineral may be gained from the two analyses quoted below. The first is of crystals from Miask, Ural, and the second of a black massive variety from Douglas Co., Colo.

	I	II
SiO_2	30.81	31.13
Al_2O_3	16.25	11.44
Fe_2O_3	6.29	6.24
Ce_2O_3	10.13	12.50
BeO	.....	.27
Di_2O_3	3.43	10.98
La_2O_3	6.35	
Y_2O_3	1.24	
FeO	8.14	13.59
MnO	2.25	.61
MgO	.13	.16
CaO	10.43	9.44
K_2O	.53	tr.
Na_2O	.....	.56
H_2O	2.79	2.78
CO_2	.....	.21
Total	98.77	99.81

Allanite rarely occurs in crystals, but when these are found they are usually more complex than those of piedmontite but much less complicated than those of epidote. Their axial ratio is 1.5509 : 1 : 1.7691 with $\beta = 64° 59'$. Their habit is like that of epidote crystals. Common forms are $\infty P\bar{\infty}(100)$, $oP(001)$, $\infty P(110)$. Twins are like those of epidote. The mineral usually occurs as massive, granular or columnar aggregates, or as ill-defined columnar crystals resembling rusty nails. It sometimes forms parallel intergrowths with epidote.

It is black on a fresh fracture and rusty brown on exposed surfaces, and has a greenish gray or brown streak. It has a glassy luster and is translucent in thin splinters, with greenish gray or brownish tints and is pleochroic in various shades of brown. Its hardness is 5–6 and density 3–4, both varying with freshness and composition. The cleavages are imperfect and the fracture uneven. Its indices of refraction are nearly the same as those of epidote.

Small fragments of fresh allanite fuse to a blebby black magnetic glass before the blowpipe and are decomposed by HCl with the separation of gelatinous silica.

Allanite is distinguished by its color, manner of occurrence, and the reaction for water in the closed tube.

The mineral alters readily on exposure to the weather, yielding among other compounds mica and limonite.

Occurrence.—Allanite occurs as an original constituent in some granites, and other coarse-grained rocks. It is found also in gneisses, occasionally in volcanic rocks and rarely as a metamorphic mineral in crystalline limestones.

Localities.—The best crystals have been found in the druses of a volcanic rock at Lake Laach, Prussia; in coarse-grained granitic rocks at several places in the Tyrol; in the limestone at Pargas, Finland; and at various points in Ural, Russia. Massive allanite occurs in the coarse granite veins at Hitterö, Norway and as the constituents of granites at many places in the United States. Parallel intergrowths with epidote are found in granite at Ilchester, Md.

CHONDRODITE GROUP

The chondrodite group of minerals includes four members of the general formula $(Mg(F \cdot OH)_2)Mg_x(SiO_4)_y$ in which x equals 1, 3, 5, 7, and y, 1, 2, 3, 4. Of these, one (humite) may be orthorhombic. The other three are monoclinic with the angle $\beta = 90°$. The four members of the group with their compositions and axial ratios are:

Prolectite	$(Mg(F \cdot OH)_2)Mg(SiO_4)$	1.0803 : 1 : 1.8862	$\beta = 90°$
Chondrodite	$(Mg(F \cdot OH)_2)Mg_3(SiO_4)_2$	1.0863 : 1 : 3.1445	$\beta = 90$
		$\bar{b}$ $\breve{a}$	
Humite	$(Mg(F \cdot OH)_2)Mg_5(SiO_4)_3$	1.0802 : 1 : 4.4033	
Clinohumite	$(Mg(F \cdot OH)_2)Mg_7(SiO_4)_4$	1.0803 : 1 : 5.6588	$\beta = 90$

To show the similarity in the ratios between the lateral axes of the four minerals, the $\breve{a}$ axis of humite is written as 1. Chondrodite, humite and clinohumite frequently occur together. Chondrodite has been reported at more localities than either humite or clinohumite, but it is not certain that much of it is not clinohumite. The three minerals resemble one another very closely. They are relatively unstable under conditions prevailing at moderate depths in the earth's crust, passing easily into serpentine, brucite or dolomite. Only chondrodite is described.

Chondrodite ($Mg_3(Mg(F \cdot OH)_2)(SiO_4)_2$)

Chondrodite is a rather uncommon mineral that occurs mainly as a constituent of metamorphosed limestones that have been penetrated by gases and water emanating from igneous rocks. It is a characteristic contact mineral.

Its composition varies somewhat in consequence of the fact that OH and F possess the power to mutually replace one another. The two analyses below are typical of varieties containing a maximum amount of F.

	SiO_2	MgO	FeO	H_2O	F	F=O	Total
I.	33.77	57.98	3.96	1.37	5.14 = 102.22	− 2.16	100.06
II.	35.42	54.22	5.72	....	9.00 = 104.36	− 3.78	100.58

I. Crystals from limestone inclusions in the lava of Vesuvius.
II. Grains separated from the limestone of the Tilly Foster Iron Mine, Brewster, N. Y.

Chondrodite is monoclinic (prismatic class), with an axial ratio 1.0863 : 1 : 3.1445. $\beta = 90°$. The crystals vary widely in habit and are often complex. The forms oP(001), $\infty P\bar{\infty}$ (100), $\infty P\breve{\infty}$ (010) and various unit and clinohemipyramids of the general symbol $xP\breve{2}$ are frequently present, but other forms are also common (Fig. 181). Twinning about oP(001) is also common. Usually, however, the mineral occurs in little rounded grains, in some instances showing crystal faces, scattered through limestone.

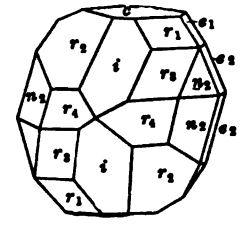


FIG. 181.—Chondrodite Crystal with oP, 001 (*c*); $\frac{1}{2}P\breve{\infty}$, 012 (*i*); $\frac{2}{3}P\breve{2}$, $\bar{1}27$ (r_1); $\frac{2}{3}P\breve{2}$, $\bar{1}25$ (r_2); $\frac{2}{3}P\breve{2}$, $\bar{1}23$ (r_3); $-2P\breve{2}$, 121 (r_4); $-P$, 111 (n_2); P, $\bar{1}11$ ($-n_2$); $\frac{1}{2}P\bar{\infty}$, $\bar{1}03$ (e_1); $P\bar{\infty}$, $\bar{1}01$ ($-e_2$) and $-P\bar{\infty}$, 101 (e_2). The *a* axis runs from right to left and the upper left hand octant is assumed to be minus.

When fresh, chondrodite has a glassy luster, is translucent and is white or has a light or dark yellow, brown or garnet color. It has a distinct cleavage parallel to oP(001), a conchoidal fracture, a hardness of 6 and a density of 3.15. Its refractive indices for yellow light are: $\alpha = 1.607$, $\beta = 1.619$, $\gamma = 1.639$.

Before the blowpipe chondrodite bleaches without fusing. With acids it decomposes with the production of gelatinous silica.

It weathers readily to serpentine, chlorite and brucite, and consequently many grains are colored dark green or black.

Occurrence.—Chondrodite, as has been stated, occurs in metamorphosed limestones. It also occurs in sulphide ore bodies and in a few instances in magnetite deposits. It is probably in all cases a pneumatolytic or metamorphic product.

Localities.—It is found as crystals in the blocks enclosed in the lavas of Vesuvius; in the copper mines of Kapveltorp, Sweden; in limestone in the Parish of Pargas, Finland; and at the Tilly Foster Iron Mine, at Brewster, N. Y. It occurs as grains in the crystalline limestone of Sussex Co., N. J., and Orange Co., N. Y.

DATOLITE GROUP

The members of the datolite group are four in number, but of these only two, viz., *datolite* ($Ca(B \cdot OH)SiO_4$) and *gadolinite* ($Be_2Fe(YO)_2(SiO_4)_2$) are of sufficient importance to be described here. Both minerals crystallize similarly in the monoclinic system (monoclinic prismatic class), with axial ratios that are nearly alike.

Datolite $a : b : c = .6345 : 1 : 1.2657 \quad \beta = 89° 51'$
Gadolinite $a : b : c = .6273 : 1 : 1.3215 \quad \beta = 89° 26\frac{1}{2}'$

Datolite ($Ca(B \cdot OH)SiO_4$)

Datolite, or datholite, is characteristically a vein mineral.

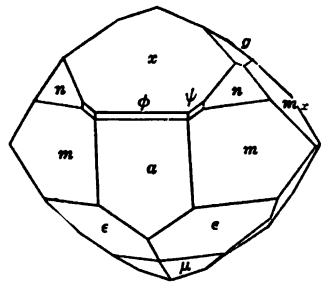


FIG. 182.—Datolite Crystal with $\infty P\bar{\infty}$, 100 (*a*); ∞P, 110 (*m*); $-P\bar{\infty}$, 101, (*φ*); $-\frac{1}{2}P\bar{\infty}$, 102 (*x*); $-P$, 111 (*n*); $-P\bar{2}$, 212 (*ϑ*); $P\tilde{\infty}$, 011 (m_x) and $\frac{1}{2}P\tilde{\infty}$, 012 (*g*).

The composition corresponding to the formula given above is:

$SiO = 37.54$; $B_2O_3 = 21.83$; $CaO = 35.00$; $H_2O = 5.63$. Total $= 100.00$

Some specimens contain a little Al_2O_3 and Fe_2O_3 but, in general, crystals that have been analyzed give results that are in close accord with the theoretical composition.

The mineral crystallizes in fine crystals that are often very complicated (Fig. 182). About 115 different forms have been observed on them. Because of the suppression of some faces by irregular growth many of the crystals are columnar in habit, others are tabular. Most crystals, however, are nearly equi-dimensional. The angle

$110 \wedge 1\bar{1}0 = 64° 40'$. The mineral occurs also in globular, radiating, granular and massive forms.

Datolite is colorless or white, when pure, and transparent. Often, however, it is greenish, yellow, reddish or violet, and translucent. Its streak is white and its luster glassy. It has no distinct cleavage. Its fracture is conchoidal. Its hardness is 5 and its sp. gr. about 3. Some crystals are pyroelectric. For yellow light, $\alpha = 1.6246$, $\beta = 1.6527$, $\gamma = 1.6694$.

Before the blowpipe it swells, and finally melts to a clear glass and, at the same time, it colors the flame green. Its powder before heating reacts strongly alkaline. After heating this reaction is weaker. The mineral loses water when strongly heated, and yields gelatinous silica when treated with hydrochloric acid.

The mineral is characterized by its crystallization, its easy fusibility and the flame reaction for boron.

Synthesis.—Datolite has not been produced artificially.

Occurrence, Origin and Localities.—It occurs on the walls of clefts in igneous rocks, in pegmatite veins and associated with metallic compounds in ore veins. It is found in many ore deposits of pneumatolytic origin, notably at Andreasberg in the Harz Mts.; at Markirch, in Alsace; in the Seisser Alps, in Tyrol; in the Serra dei Zanchetti in the Bolognese Apennines; at Arendal, Norway, and at many other places. In North America it occurs at Deerfield, Mass.; at Tariffville, Conn.; at Bergen Hill, N. J.; and at several points in the copper districts of the Lake Superior region.

Gadolinite ($Be_2Fe(YO)_2(SiO_4)_2$)

Gadolinite is a rather rare mineral with a composition that is not well established. Its occurrence is limited to coarse granite veins or dikes—pegmatites—of which it is sometimes a constituent.

Its theoretical composition is as follows, on the assumption that it is analogous to that of datolite:
$SiO = 25.56$; $Y_2O_3 = 48.44$; $FeO = 15.32$; $BeO = 10.68$. Total $= 100.00$, but nearly all specimens contain cerium oxides. Others contain notable quantities of erbium or lanthanum oxides and small quantities of thorium oxide. Nearly all show the presence of Fe_2O_3, Al_2O_3, CaO and MgO, and in some helium has been found.

The mineral is found massive and in rough crystals with an axial ratio $a : b : c = .6273 : 1 : 1.3215$. $\beta = 89° 26\frac{1}{2}'$. The crystals show comparatively few forms, of which $\infty P(110)$, $oP(001)$, $P\bar{\infty}(011)$,

$\frac{1}{2}P\bar{\infty}$ (012), P($\bar{1}$11) and $-$P(111) are the most common. They are usually columnar in habit and are rough and coarse. The angle $110 \wedge 1\bar{1}0 = 64° \ 12'$.

Gadolinite is usually black or greenish black and opaque or translucent, but very thin splinters of fresh specimens are translucent or transparent in green tints. Its luster is glassy or resinous, streak greenish gray and fracture conchoidal. Its hardness is 6–7 and its density about 4–4.5. Upon heating the density increases. Many crystals appear to be made up of isotropic and anisotropic substance, and some to consist entirely of isotropic matter. This phenomenon has been explained in a number of different ways, but no one is entirely satisfactory. In general, the isotropic material is believed to be an amorphous alteration form of the anisotropic variety. It may be changed into the anisotropic form by heating.

The crystallized gadolinite swells up in the blowpipe flame without becoming fused and retains its transparency. The amorphous variety also swells without melting, but yields a grayish green translucent mass. The mineral phosphoresces when heated to a temperature between that of melting zinc and silver. After phosphorescing it is unattacked by hydrochloric acid. Before heating it gelatinizes with the same reagent. The mineral is weakly radioactive.

Localities and Origin.—Gadolinite occurs in the pegmatites of Ytterby near Stockholm, and of Fahlun, Sweden; on the Island of Hitterö, in southern Norway; in the Radauthal, in Harz; at Barringer Hill, Llano Co., Texas, as nodular masses and large rough crystals; and at Devil's Head, Douglas Co., Colo. In the last locality it occurs in a decomposed granite as a black isotropic variety with a very complex composition. Specimens analyzed as follows:

	I	II		I	II
SiO_2	22.13	21.86	FeO	10.43	11.36
ThO_2	.89	.81	BeO	7.19	5.46
Al_2O_3	2.34	.54	CaO	.34	.47
Fe_2O_3	1.13	3.59	H_2O	.86	.74
Ce_2O_3	11.10	6.87	Other	.60	.79
$(La \cdot Di)_2O_3$	21.23	19.10			
Y_2O_3	9.50	12.63	Total	100.48	100.02
Er_2O_3	12.74	15.80			

It has apparently in some cases solidified from an igneous magma. In others it is of pneumatolytic origin.

Staurolite ($Fe(AlOH)(AlO)_4(SiO_4)_2$)

Staurolite is a mineral that is interesting from the fact that it frequently forms twinned crystals that resemble a cross in shape, and which consequently, during the Middle Ages, was held in great veneration. Its composition is not well established. The composition indicated by the formula above is as shown in the first line below (I). Three analyses are quoted in the next three lines:

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	H_2O	TiO_2	Total
I.	26.3	55.9	....	15.8	....	2.00	...	100.00
II.	27.38	54.20	6.83	9.13	....	1.43	...	98.97
III.	30.23	51.16	....	14.66	2.73	1.26	.29	100.33
IV.	27.91	52.92	6.87	7.80	3.28	1.59	...	100.37

I. Theoretical composition.
II. From Monte Campione, Switzerland.
III. From Morbihan, France.
IV. From Chesterfield, Mass.

Staurolite crystallizes in the orthorhombic system (bipyramidal class) in simple crystals with the axial ratio .4734 : 1 : .6828. The indi-

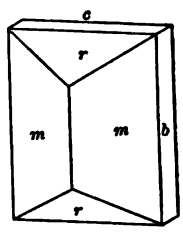


FIG. 183.

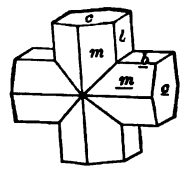


FIG. 184.

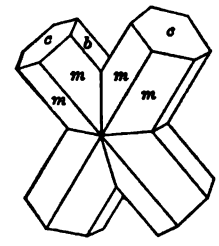


FIG. 185.

FIG. 183.—Staurolite Crystal with ∞P, 110 (*m*); ∞P$\bar{\infty}$, 100 (*b*); oP, 001 (*c*) and P$\bar{\infty}$, 101 (*r*).

FIG. 184.—Staurolite Crystal Twinned about $\frac{3}{2}$P$\breve{\infty}$ (032).

FIG. 185.—Staurolite Crystal Twinned about $\frac{3}{2}$P$\breve{\frac{3}{2}}$ (232).

vidual crystals are usually bounded by ∞P(110), ∞P$\bar{\infty}$ (001), P$\bar{\infty}$ (101) and often oP(001), but all their faces are rough (Fig. 183). The angle $110 \wedge 1\bar{1}0 = 50° 40'$. More common, however, than the simple crystals are interpenetration twins. The most common of these are of two kinds, (1) with $\frac{3}{2}$P$\breve{\infty}$ (032) the twinning plane (Fig. 184), and (2) with $\frac{3}{2}$P$\breve{\frac{3}{2}}$(232) the twinning plane (Fig. 185). Both types of twins yield crosses, but the arms of the first type are perpendicular to one another and those of

the second type make angles of about 60° and 120°. Sometimes the twinning is repeated, giving rise to trillings.

The mineral is reddish or blackish brown, and has a glassy or greasy luster. Its streak is white. It is slightly translucent in fresh crystals, but usually is opaque. In very thin pieces it is pleochroic in hyacinth-red and golden yellow tints. Its cleavage is distinct parallel to $\infty P\bar{\infty}$ (010) and indistinct parallel to ∞P(110). Its fracture is conchoidal, its hardness 7 and its density 3.4–3.8. For yellow light, $\alpha = 1.736$, $\beta = 1.741$, $\gamma = 1.746$.

Before the blowpipe staurolite is infusible, unless it contains manganese, in which case it fuses to a black magnetic glass. It is only slightly attacked by sulphuric acid.

It is distinguished from other minerals by its crystallization, infusibility and hardness.

Staurolite weathers fairly readily into micaceous minerals, such as chlorite (p. 428) and muscovite (p. 355).

Synthesis.—It has not been produced in the laboratory.

Occurrence.—The mineral occurs principally in mica schist and other schistose rocks where it is the result of regional or contact metamorphism. Because of its method of occurrence it frequently contains numerous mineral inclusions, among them garnet and mica.

Localities.—Good crystals of staurolite are found in the schists at Mte. Campione, Switzerland; in the Zillerthal, Tyrol; at Aschaffenburg, in Bavaria; at various places in Brittany, France; and in the United States, at Windham, Maine, at Franconia, N. H., at Chesterfield, Mass., in Patrick Co., Va., and in Fannin Co., N. C.

Uses.—Twins of staurolite are used, to a slight extent, as jewelry. Specimens from Patrick Co., Virginia, are mounted and worn as charms under the name of "Fairy Stones."

Dumortierite ($Al(AlO)_7H(BO)(SiO_4)_3$)

Dumortierite is one of the few blue silicates known. It is a borosilicate with a composition approaching the formula indicated above. The analysis of a sample from Clip, Arizona, gave (I):

	SiO_2	Al_2O_3	Fe_2O_3	Ti_2O_3	MgO	B_2O_3	P_2O_5	Loss on Ign.	Total
I.	27.99	64.49	...		tr	4.95	.20	1.72	99.35
II.	28.58	63.31	.21	1.49	....	5.21	...	1.53	100.33

Specimens from California (II) contain in addition notable quantities of TiO_2, which is thought to exist as Ti_2O_3 replacing a part of the Al_2O_3.

The mineral crystallizes in the orthorhombic system in aggregates of fibers, needles or very thin prisms exhibiting only $\infty P(110)$ and $\infty P\bar{\infty}(100)$ without end faces. Its axial ratio is $a : b = .5317 : 1$, and the prismatic angle $110 \wedge 1\bar{1}0 = 56°$. Its crystals possess a distinct cleavage parallel to $\infty P\bar{\infty}(100)$ and a fracture perpendicular to the long axes of the prisms. Twinning is common, with $\infty P(110)$ the twinning plane.

Dumortierite is commonly some shade of blue, but in some cases is green, lavender, white, or colorless. It is translucent or transparent and strongly pleochroic, being colorless and red, purple or blue. Its streak is light blue. Hardness is 7 and density 3.3. Its refractive indices for yellow light are: $\alpha = 1.678$, $\beta = 1.686$, $\gamma = 1.689$.

Before the blowpipe the mineral loses its color and is infusible. It is insoluble in acids.

It is distinguished from other blue silicates by its fibrous or columnar character and its insolubility in acids.

Its principal alteration products are kaolin and damourite (pp. 404, 357).

Occurrence and Localities.—Dumortierite occurs only as a constituent of gneisses and pegmatites. It is found in pegmatite near Lyons, France; near Schmiedeberg, in Silesia; at Harlem, N. Y.; in a granular quartz, at Clip, Yuma Co., Ariz., and in a dike rock composed of quartz and dumortierite, near Dehesa, San Diego Co., Cal. It is evidently a pneumatolytic mineral. Its common associates are kyanite, andalusite or sillimanite.

SODALITE GROUP

The sodalite group includes a series of isometric minerals that may be regarded as compounds of silicates with a sulphate, a sulphide or a chloride, or, perhaps better, as silicates in which are present radicals containing Cl, SO_4 and S. The minerals comprising the group are *haüynite*, *nosean*, *sodalite* and *lasurite*. Of these, sodalite appears to be a mixture of $3NaAlSiO_4$ and NaCl, in which the Cl has combined with one atom of Al, thus $Na_4(ClAl)Al_2(SiO_4)_3$. The other members of the group are comparable with this on the assumption that the Cl atom is replaced by the radicals $NaSO_4$, and NaS_3. It is possible, however, that all are molecular compounds as indicated by the second set of formulas given below. All are essentially sodium salts, except that in typical haüynite a portion of the Na is replaced by Ca. The chemical symbols of the four minerals with the calculated percentages of silica, alumina and soda corresponding to their formulas are:

		SiO_2	Al_2O_3	Na_2O
Sodalite	$Na_4(Cl \cdot Al)Al_2(SiO_4)_3$, or $3NaAlSiO_4 \cdot NaCl$	37.14	31.60	25.60
Noselite	$Na_4(NaSO_4 \cdot Al)Al_2(SiO_4)_3$, or $3NaAlSiO_4 \cdot Na_2SO_4$	31.65	27.03	27.26
Haüynite	$(Na_2Ca)_2(NaSO_4 \cdot Al)Al_2(SiO_4)_3$, or $3NaAlSiO_4 \cdot CaSO_4$	31.99	27.32	16.53
Lasurite	$Na_4(NaS_3 \cdot Al)Al_2(SiO_4)_3$, or $3NaAlSiO_4 \cdot Na_2S \cdot S_x$	31.7	26.9	27.3

Sodalite ($Na_4(Cl \cdot Al)Al_2(SiO_4)_3$)

Sodalite, theoretically, is the pure sodium compound corresponding to the composition indicated by the formula given above. Natural crystals, however, usually contain a little potassium in place of some of the sodium and often some calcium, as indicated by the analyses of material from Montreal, Canada (I), and Litchfield, Maine (II), quoted below. Moreover, their content of Cl is not constant.

	SiO_2	Al_2O_3	Na_2O	K_2O	CaO	Cl			Cl=O	Total
I.	37.52	31.38	25.15	.78	.35	6.91	=	102.09	−1.55	100.54
II.	37.33	31.87	24.56	.10	...	6.83	=	101.76*	−1.54	100.22

* Includes 1.07 per cent H_2O.

Sodalite occurs massive and in crystals that appear to be holohedral, but etch figures indicate that they are probably tetrahedrally hemihedral (hextetrahedral class). Most crystals are dodecahedral in habit, though some are tetrahexahedral and others octahedral. The forms usually developed are ∞O(110), ∞O∞ (100), O(111), 2O2(112) and 4O4(114). Interpenetration twins of two dodecahedrons are common, with O the twinning plane (Fig. 186). These often possess an hexagonal habit.

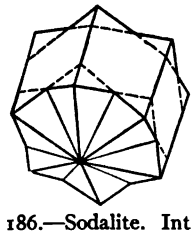


FIG. 186.—Sodalite. Interpenetration Twin of Two Dodecahedrons Elongated in the Direction of an Octahedral Axis and Twinned about O(111).

The mineral is colorless, white or some light shade of blue or red, and its streak is white. Its luster is vitreous. It is transparent, translucent and sometimes opaque. Its cleavage is perfect parallel to ∞O(110) and its fracture conchoidal. Its hardness is 5–5.6, and its density 2.3. Its refractive index for yellow light, $n = 1.4827$. Some specimens are distinctly fluorescent and phosphorescent.

Before the blowpipe, colored varieties bleach and all varieties swell and fuse readily to a colorless blebby glass. The mineral dissolves completely in strong acids and yields gelatinous silica, especially after heating. When dissolved in dilute nitric acid its solution yields a chlorine precipitate with silver nitrate. Its powder becomes brown on treatment with $AgNO_3$, in consequence of the production of AgCl.

The mineral is best distinguished from other similarly appearing minerals by the production of gelatinous silica with acids and the reaction for chlorine.

As a result of weathering sodalite loses Cl and Na and gains water. Its commonest alteration products are zeolites (p. 445), kaolin (p. 440), and muscovite (p. 355).

Syntheses.—It has been produced artificially by dissolving nepheline powder in fused sodium chloride, and by decomposing muscovite with sodium hydroxide and NaCl at a temperature of 500° C.

Occurrence and Origin.—Sodalite occurs principally as a constituent of igneous rocks rich in alkalies and as crystals on the walls of pores in some lavas. It is also known as an alteration product of nepheline.

Localities.—Good crystals are found in nepheline syenite at Ditrò, in Hungary, in the lavas of Mte. Somma, Italy; in the pegmatites of southern Norway; and at many other points where nepheline rocks occur. In North America it is abundant in the rocks at Brome, near Montreal; in the Crazy Mts., Montana, and at Litchfield, Maine. The material at the last-named locality is light blue.

Noselite and Haüynite ($(Na_2Ca)_2(NaSO_4 \cdot Al)Al_2(SiO_4)_3$)

Noselite, or nosean, and haüynite, or haüyn, consist of isomorphous mixtures of sodium and calcium molecules of the general formula given above. Those mixtures containing a small quantity of calcium are usually called nosean, while those with larger amounts constitute haüyn. The theoretical nosean and haüyn molecules are indicated on p. 340. The theoretical compositions of the pure nosean molecule (I) and of the most common haüyn mixture (II) are as follows:

	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	Ka_2O	SO_3	H_2O	Total
I.	31.65	27.03	...	.....	27.26	....	14.06	....	100.00
II.	31.99	27.32	...	9.94	16.53	....	14.22	....	100.00
III.	35.99	29.41	.31	.21	20.91	....	10.58	1.63	99.61*
IV.	33.78	27.42	...	10.08	13.26	3.23	12.31	....	100.08

* Contains also .57 per cent Cl.

In line III is the analysis of a blue nosean from Siderao, Cape Verde, and in line IV, the analysis of a blue haüyn from the lava of Monte Vulture, near Melfi, Italy.

Nosean and haüyn are isomorphous with sodalite. They crystallize is the isometric system in simple combinations with a dodecahedral habit. The principal forms observed are $\infty O(110)$, $\infty O\infty(100)$ $\infty O2(102)$, $O(111)$ and $2O2(112)$. Contact and interpenetration twins are common, with $O(111)$ the twinning plane. The twins are often columnar.

The minerals have a glassy or greasy luster, are transparent or translucent, have a distinct cleavage parallel to $\infty O(110)$ and an uneven or conchoidal fracture. Their hardness is 5.6 and density 2.25 to 2.5, the value increasing with the amount of CaO present. Nosean is generally gray and haüyn blue, but both minerals may possess almost any color, from white through light green and blue tints to black. Red colors are rare. The streaks of both minerals are colorless, or bluish. For yellow, light $n=1.4890$ to 1.5038, increasing with increase in the Ca present. Both minerals are fluorescent and phosphorescent.

Before the blowpipe both minerals fuse with difficulty to a blebby white glass, the blue haüyn retaining its color until a high temperature is reached. In this respect it differs from blue sodalite which bleaches at comparatively low temperatures. Upon treatment with hot water both minerals yield Na_2SO_4. They are decomposed with acids yielding gelatinous silica. The powders of both minerals react alkaline. Both also give the sulphur reaction with soda on charcoal.

The minerals are easily distinguished from all others by their crystallization, gelatinization with acids and reaction for sulphur.

Both minerals upon weathering yield kaolin or zeolites and calcite.

Synthesis.—Crystals of noselite have been made by melting together Na_2CO_3, kaolinite and a large excess of Na_2SO_4.

Occurrence.—Haüyn and nosean occur in many rocks containing nepheline, especially those of volcanic origin and in a few metamorphic rocks. Haüyn is so common in some of them as to constitute an essential component.

Localities.—Both minerals are found in good crystals in metamorphosed inclusions in the volcanic rocks of the Lake Laach region, in Prussia; also in the rocks of the Kaiserstuhl, in Baden; in those of the Albanian Hills, in Italy, and at S. Antao in Cape Verde. In America haüyn has been reported from the nepheline rocks of the Crazy Mts., Montana.

Lasurite ($Na_4(NaS_3 \cdot Al)Al_2(SiO_4)_3$)

Lasurite is better known as lapis lazuli. It is bright blue in color and was formerly much used as a gem stone. The material utilized for gem purposes is usually a mixture of different minerals, but its blue color is given it by a substance with a composition corresponding to the formula indicated above. Since the artificial ultramarine, which is ground and used as a pigment, also has this composition, the molecule is sometimes represented by the shortened symbol US_3, or if it contains but two atoms of S, by the symbol US_2. The deep blue lasurite from Asia contains as its coloring material a substance with a composition that may be represented by 15.7 molecules of US_3, 76.9 molecules of haüyn and 7.4 molecules of sodalite, corresponding to the percentages:

SiO_2	Al_2O_3	CaO	Na_2O	K_2O
32.52	27.61	6.47	19.45	.28
SO_3	S	Cl	Total	(Less Cl = O)
10.46	2.71	.47	99.97	= 99.42

Lasurite is thus the name given to the blue coloring matter of lapis lazuli, which is a mixture. It apparently crystallizes in dodecahedrons. Its streak is blue, its cleavage is dodecahedral, its hardness about 5 and its specific gravity about 2.4. Before the blowpipe it fuses to a white glass. Its powder bleaches rapidly in hydrochloric acid, decomposes with the production of gelatinous silica and yields H_2S.

It is distinguished from blue sodalite and haüyn by the reaction with HCl, especially by the evolution of H_2S.

Occurrence.—Lasurite is principally a contact mineral in limestone.

Localities.—Good lapis lazuli occurs at the end of Lake Baikal, in Siberia; in the Andes of Ovalle, in Chile; in the limestone inclusions in the lavas of Vesuvius, and in the Albanian Mts., Italy.

Uses.—Lapis lazuli is used as an ornamental stone in the manufacture of vases, and various ornaments, in the manufacture of mosaics, and as a pigment, when ground, under the name ultramarine. Most of the ultramarine at present in use, however, is artificially prepared.

ACID ORTHOSILICATES

Prehnite ($H_2Ca_2Al_2(SiO_4)_3$)

Prehnite is nearly always found in crystals, though it occurs also in stalactitic and granular masses.

The theoretical composition of the pure mineral is $SiO_2 = 43.69$,

$Al_2O_3 = 24.78$, $CaO = 27.16$, and $H_2O = 4.37$. Most crystals, however, contain small quantities of Fe_2O_3 and other constituents.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	H_2O	Total
Jordansmühl, Silesia.....	44.12	26.00	.61	....	25.26	tr	4.91	100.90
Cornwall, Penn.....	42.40	20.88	5.54	....	27.02	tr	4.01	99.85
Chlorastrolite, Isle Royale	37.41	24.62	2.21	1.81	22.20	3.46	7.72	99.75*

* Also .32 per cent Na_2O.

Its crystallization is orthorhombic and hemimorphic (rhombic pyramidal class), with $a : b : c = .8420 : 1 : 1.1272$. The crystals vary widely in habit, but they contain comparatively few forms. The most prominent are oP(001), ∞P(110), 6P$\bar{\infty}$(061), 2P(221) and 6P(661) (Fig. 187). The angle $110 \wedge 1\bar{1}0 = 80° 12'$. Because they exhibit pyroelectric polarity in the direction of the *a* axis the crystals are thought to be twins, with ∞P$\bar{\infty}$(100) as the twinning plane. Cleavage is good parallel to oP(001).

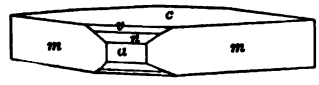


FIG. 187.—Prehnite Crystal with ∞P, 110 (*m*); ∞P$\bar{\infty}$, 100 (*a*); $\frac{3}{4}$P$\bar{\infty}$, 304 (*n*); $\frac{3}{8}$P$\bar{\infty}$, 308 (*v*) and oP, 001 (*c*).

The crystals are frequently tabular parallel to oP(001), although other habits are also common. Isolated individuals are rare, usually many are grouped together into knotty or warty aggregates.

Prehnite is colorless or light green, and transparent or translucent, and it has a colorless streak. Its luster is pearly on oP(001) but glassy on other faces. Its fracture is uneven, its hardness 7+ and its density 2.80–2.95. For yellow light, $\alpha = 1.616$, $\beta = 1.626$, $\gamma = 1.649$.

Before the blowpipe prehnite exfoliates, bleaches and melts to a yellowish enamel. At a high temperature it yields water. Its powder is strongly alkaline. It is partially decomposed by strong hydrochloric acid with the production of pulverulent silica. After fusion it dissolves readily in this acid yielding gelatinous silica.

The mineral has not been produced artificially.

Occurrence.—Prehnite occurs as crystals implanted on the walls of clefts in siliceous rocks, in the gas cavities in lavas, and in the gangue of certain ores, especially copper ores. It is found also as pseudomorphs after analcite (p. 458), laumonite (p. 451), and natrolite (p. 454). In all cases it is probably a secondary product.

Localities.—Fine crystals come from veins at Harzburg, in Thüringia; at Striegau and Jordansmühl, Silesia, and at Fassa and other places in Tyrol. Good crystals are found also in the Campsie Hills in Scotland. The mineral is abundant in veins with copper along the north shore of

Lake Superior and on Keweenaw Point, and it occurs also at Farmington, Conn.; Bergen Hill, N. J.; and Cornwall, Penn.

Uses.—The mineral known as *chlorastrolite* is probably an impure prehnite. It is found on the beaches of Isle Royale and the north shore of Lake Superior as little pebbles composed of stellar and radial bunches of bluish green fibers. The pebbles were originally the fillings of gas cavities in old lavas. They are polished and used, to a slight extent, as gem-stones. About $2,000 worth were sold in 1911 and $350 worth in 1912.

Axinite ($H(Ca \cdot Fe \cdot Mn)_3Al_2B(SiO_4)_4$)

Axinite is especially noteworthy for its richness in crystal forms. The mineral is a complicated borosilicate for which the formula given above is merely suggestive. Analyses of crystals from different localities vary so widely that no satisfactory simple formula has been proposed for the mineral. Four recent analyses are quoted below:

	Radauthal	Striegau	Oisans	Cornwall
SiO_2	39.26	42.02	41.53	42.10
B_2O_3	4.91	5.00	4.62	4.64
Al_2O_3	14.46	17.73	17.90	17.40
Fe_2O_3	2.62	.93	3.90	3.06
FeO	3.65	6.55	4.02	5.84
MnO	2.80	6.52	3.79	4.63
CaO	29.70	19.21	21.66	20.53
MgO	2.00	.38	.74	.66
H_2O	1.22	1.77	2.16	1.80
Total	100.62	100.11	100.32	100.66

Axinite crystallizes in the triclinic system (pinacoidal class), with $a : b : c = .4921 : 1 : .4797$ and $\alpha = 82° 54'$, $\beta = 91° 52'$, $\gamma = 131° 32'$. The crystals are extremely varied in habit but nearly all are somewhat tabular parallel to $'P(1\bar{1}1)$, $\infty P'(110)$ or $\infty 'P(1\bar{1}0)$. About 45 forms have been observed. In addition to the three mentioned, $2'P' \breve{\infty}$ (201), $P'(111)$, $_{,}P(1\bar{1}\bar{1})$, $2_{,}P' \breve{\infty}$ (021), $\infty P \breve{\infty}$ (010) and $\infty P \bar{\infty}$ (100) are the most frequently met with (Figs. 188, 189). The plane $'P(1\bar{1}1)$ is usually striated parallel to its intersection with $\infty 'P(1\bar{1}0)$. The angle $100 \wedge 1\bar{1}0 = 15° 34'$. The cleavage is indistinct parallel to $\infty P'(110)$ and the crystals are strongly pyro electric.

Axinite is brownish, gray, green, bluish or pink, and is strongly pleochroic in pearl-gray, olive-green and cinnamon-brown tints. It is

transparent or translucent and has a glassy luster and a colorless streak. Its fracture is conchoidal or uneven. It is brittle, has a hardness of 6–7 and a density of 3.3. For red light, $\alpha = 1.6720$, $\beta = 1.6779$, $\gamma = 1.6810$.

Axinite, before the blowpipe, exfoliates and fuses to a dark green glass which becomes black in the oxidizing flame. It colors the flame green, especially upon the addition of $KHSO_4$ and CaF_2 to its powder. Its powder reacts alkaline. It is only slightly attacked by acids. After

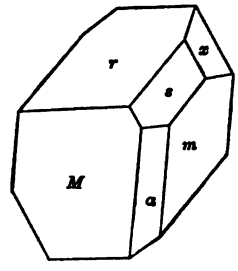


FIG. 188.

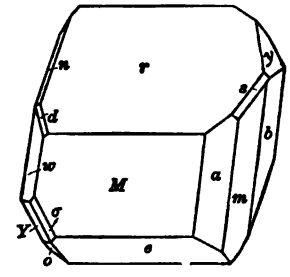


FIG. 189.

FIG. 188.—Axinite Crystal with $\infty P \bar{\infty}$, 100 (*a*); $2'P' \bar{\infty}$, 201 (*s*); $\infty P,'$, 110 (*m*); $\infty,'P$, $1\bar{1}0$ (*M*); P′, 111 (*x*) and 'P, $1\bar{1}1$ (*r*).

FIG. 189.—Axinite Crystal with *M*, *m*, *a*, *r* and *s* as in Fig. 188. Also $\infty P \breve{\infty}$, 010 (*b*); $2P' \breve{\infty}$, 021 (*y*); ,P, $\bar{1}11$ (*e*); $\frac{4}{3},P\breve{3}$, $\bar{1}32$ (*o*); $4,P\breve{2}$, $\bar{2}41$ (*σ*); $3,P\breve{3}$, $\bar{1}31$ (*Y*); $\infty,'P\breve{3}$, $1\bar{3}0$ (*w*); $3'P\breve{3}$, $1\bar{3}1$ (*n*) and $4'P\breve{2}$, $2\bar{4}1$ (*d*).

fusion, however, it dissolves readily with the production of gelatinous silica.

The mineral is easily characterized by its crystallization and the green color it imparts to the flame.

It has not been produced artificially.

Pseudormorphs of chlorite after axinite have been found in Dartmoor, England.

Occurrence.—Axinite crystals occur in cracks in old siliceous rocks. It is found also in ore veins and as a component of a contact rock composed mainly of augite, hornblende and quartz, occurring near the peripheries of granite and diabase masses. It was formed by the aid of pneumatolytic processes.

Localities.—Excellent crystals of axinite are found at Andreasberg and other places in the Harz Mts.; near Striegau, in Silesia; near Poloma, in Hungary; at the Piz Valatscha, in Switzerland; near Vernis and at other points in Dauphiné, France; at Botallak, Cornwall, England; at Konigsberg, Norway; Nordmark, Sweden; Lake Onega, and Miask, Russia; at Wales in Maine and at South Bethlehem, Penn.

Dioptase (H_2CuSiO_4)

Dioptase is especially interesting because of its crystallization, which is rhombohedral tetartohedral (trigonal rhombohedral class). Its crystals are columnar. Their axial ratio is 1 : .5342. They are usually bounded by $\infty P2(11\bar{2}0)$, $-2R(02\bar{2}1)$ or $R(10\bar{1}1)$ and $-\frac{4P\frac{4}{3}}{4}\frac{l}{r}(13\bar{4}1)$ or $+\frac{4P\frac{4}{3}}{4}\frac{r}{l}(31\bar{4}1)$ (a rhombohedron of the third order, Fig. 190). Besides occurring as crystals the mineral is found also massive and in crystalline aggregates.

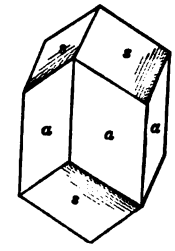


FIG. 190.—Dioptase Crystal with $\infty P2$, $11\bar{2}0$ and $-2R$, $02\bar{2}1$ (*s*), with a Rhombohedron of the 3rd Order Indicated by Striations.

The composition expressed by the formula given above is $SiO_2=38.18$; $CuO=50.40$; $H_2O=11.44$, which is approached very closely by some analyses. The same composition may be expressed by $CuSiO_3 \cdot H_2O$. Indeed, recent work indicates that the mineral is a hydrated metasilicate and not an acid orthosilicate.

Dioptase has an emerald-green or blackish green color, a glassy luster and a green streak. It is transparent or translucent, is brittle and its fracture is uneven or conchoidal. Its hardness is 5 and its density 3.05. It is weakly pleochroic and is distinctly pyroelectric. For yellow light, $\omega=1.6580$, $\epsilon=1.7079$.

Before the blowpipe dioptase turns black and colors the flame green. On charcoal it turns black in the oxidizing flame and red in the reducing flame without fusing. It is decomposed by acids with the production of gelatinous silica.

Synthesis.—Crystals of dioptase have been made by allowing mixtures of copper nitrate and potassium silicate to diffuse through a sheet of parchment paper.

Occurrence and Localities.—The mineral occurs in druses on quartz in clefts in limestone, and in gold-bearing placers in the Altyn-Tübe Mt. near the Altyn Ssu River, in Siberia; in crystals on wulfenite and calamine and embedded in clay near Rézbánya, Hungary; with quartz and chrysocolla in the Mindonli Mine, French Congo; in copper mines at Capiapo, Chile; and in Peru; at the Bon Ton Mines, Graham Co., Ariz.; and near Riverside, Pinal Co., in the same State. In the Bon Ton Mines it covers the walls of cavities in the ore, which consists of a mixture of limonite and copper oxides.

MICA GROUP

The mica group comprises a series of silicates that are characterized by such perfect cleavages that extremely thin lamellæ may be split from them with surfaces that are perfectly smooth. The lamellae are elastic and in this respect the members of the group are different from other minerals that possess an almost equally perfect cleavage. Some of the micas are of great economic importance, but most of them have found little use in the arts.

The micas may be divided into four subgroups, (1) the magnesium-iron micas, (2) the calcium micas, (3) the lithium-iron micas, and (4) the alkali micas. Of the latter there are three subdivisions, (*a*) the lithia micas, (*b*) the potash micas, and (*c*) the soda micas.

All the micas crystallize in the monoclinic system (monoclinic prismatic class), in crystals with an orthorhombic or hexagonal habit.

In composition the micas are complex. The alkali micas are apparently acid orthosilicates of aluminium and an alkali—the potash mica being $KH_2Al_3(SiO_4)_3$. Other alkali micas are more acid, and some of the magnesium-iron micas are very complex. The members with the best established compositions are apparently salts of orthosilicic acid, and, hence, the entire group is placed with the orthosilicates.

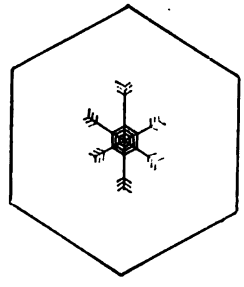


FIG. 191.—Percussion Figure on Basal Plane of Mica. The long ray is parallel to $\infty P \bar{\infty}$ (010).

All the micas possess also, in addition to the very noticeable cleavage which yields the characteristically thin lamellae that are so well known, other planes of parting which are well exhibited by the rays of the percussion figure (Fig. 191). The largest ray—known as the characteristic ray—is always parallel to the clinopinacoid. In some micas the plane of the optical axes is the clinopinacoid and in others is perpendicular thereto. In the latter, known as micas of the first order, the plane of the axes is perpendicular to the characteristic ray and in the former, distinguished as micas of the second order, it is parallel to this ray.

The value of the optical angle varies widely. In the magnesia micas it is between 0° and 15°, in the calcium micas between 100° and 120°, and in the other micas between 55° and 75°. When the angle becomes zero the mineral is apparently uniaxial. But etch figures on all micas indicate a monoclinic symmetry (compare Fig. 194).

THE MAGNESIUM-IRON MICAS

Biotite $((K \cdot H)_2(Mg \cdot Fe)_2(Al \cdot Fe)_2(SiO_4)_3)$

The magnesium-iron micas are usually designated as biotite. This group includes micas of both orders as follows:

1st Order	2d Order
Anomite	*Meroxene*
	Lepidomelane
	Phlogopite

The crystals of biotite have an axial ratio .5774 : 1 : 3.2904 with $\beta = 90°$. They are usually simple combinations of oP(001), ∞P$\bar{\infty}$ (010), $-\frac{1}{2}$P(112) and P($\bar{1}$11) (Fig. 192). Twins are common, with the twinning plane perpendicular to oP(001). The composition face may be the same as the twinning plane or it may be oP(001) (Fig. 193). The crystals have an hexagonal habit, the angle $\bar{1}11 \wedge 010$ being 60° 22½′. The mineral also occurs in flat scales and in scaly aggregates.

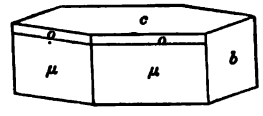


FIG. 192.—Biotite Crystal with oP, 001 (*c*); ∞P$\bar{\infty}$, 010 (*b*); *P*, $\bar{1}$11 (*μ*) and $-\frac{1}{2}$P, 112 (*o*).

The color of biotites varies from yellow, through green and brown to black. Pleochroism is strong in sections perpendicular to the perfect cleavage, i.e., perpendicular to oP(001). The streak of all varieties is white. Their hardness = 2.5 and density 2.7–3.1, depending upon composition. The refractive indices for yellow

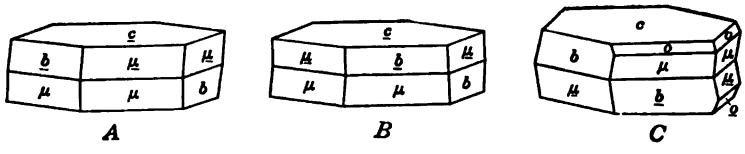


FIG. 193.—Biotite Twinned about a Plane Perpendicular to oP (001), and Parallel to the Edge Between oP(001) and -2P(221). The composition plane is oP(001). Mica law. A = right hand twin, B and C = left hand twins.

light in a light brown biotite from Vesuvius are: $\alpha = 1.5412$, $\beta = 1.5745$. They are higher in darker varieties.

Etch figures are produced by the action of hot concentrated sulphuric acid.

Varieties and their Localities.—**Anomite** is rare. It occurs at Greenwood Furnace, Orange Co., N. Y., and at Lake Baikal, in Siberia.

Meroxene is the name given to the common biotite of the 2d order. It occurs in particularly fine crystals in the limestone blocks included in the lava of Mte. Somma, Naples, Italy; at various points in Switzerland, Austria and Hungary; and at many other points abroad and in this country.

Lepidomelane is a black meroxene characterized by the presence in it of large quantities of ferric iron. It is essentially a magnesium-free biotite. It occurs in igneous rocks, especially those rich in alkalies. Two of its best known occurrences in the United States are in the nepheline syenite at Litchfield, Maine, and in a pegmatite in the northern part of Baltimore, Md.

Phlogopite, or **amber mica,** is the nearly pure magnesium biotite which by most mineralogists is regarded as a distinct mineral, partly because in nearly all cases it contains fluorine. Its color is yellowish brown, brownish red, brownish yellow, green or white. Its luster is often pearly, and it frequently exhibits asterism in consequence of the presence of inclusions of acicular crystals of rutile or tourmaline arranged along the rays of the pressure figure. Its axial angle is small, increasing with increase of iron. Its refractive indices are: $\alpha = 1.562$, $\beta = 1.606$, $\gamma = 1.606$.

Phlogopite is especially characteristic of metamorphosed limestones. It occurs abundantly in the metamorphosed limestones around Easton, Pa.; at Edwards, St. Lawrence Co., N. Y., and at South Burgess, Ontario, Canada. It is also found as a pyrogenetic mineral in certain basic igneous rocks.

Typical analyses of the four varieties of biotite follow:

	I	II	III	IV
SiO_2	40.81	35.79	32.35	39.66
TiO_2	.....	3.51	tr.	.56
Al_2O_3	16.47	13.70	17.47	17.00
Fe_2O_3	2.16	4.04	24.22	.27
FeO	5.92	17.09	13.11	.20
MnO	.....	.40	1.20	.....
CaO	1.48	.....	.....	.....
BaO	.....	.33	.....	.62
MgO	21.08	9.68	.89	26.49
Na_2O	1.55	.45	7.00	.60

	I	II	III	IV
K_2O.....	9.01	8.20	6.40	9.97
H_2O-.....	2.19	.90	4.67	.66
H_2O+.....		3.26		2.33
F.....	.....	.10	.....	2.24
Total				
(less O=F)	99.19	99.91	100.83	99.66

I. Anomite from Greenwood Furnace, Orange Co., N. Y.
II. Meroxene from granite, Butte, Mont.
III. Lepidomelane from eleolite syenite, Litchfield, Maine.
IV. Brown phlogopite from Burgess, Can.

Before the blowpipe the dark, ferruginous varieties fuse easily to a black glass; the lighter colored varieties with greater difficulty to a yellow glass. Their powder reactions are strongly alkaline. The minerals are not attacked by HCl but are decomposed by strong H_2SO_4. In the closed tube all varieties give a little water.

The biotites are distinguished from all other minerals except the other micas by perfect cleavage and from other micas by their color, solubility in strong sulphuric acid and pleochroism.

The commoner alteration products of biotite are a hydrated biotite, chlorite (p. 428), epidote, sillimanite and magnetite, if the mica is ferriferous. At the same time there is often a separation of quartz. Phlogopite alters to a hydrophlogopite and to penninite (p. 429), and talc (p. 401).

Syntheses.—The biotites are common products of smelting operations. They have been made by fusing silicates of the proper composition with sodium and magnesium fluorides.

Occurrences and Origin.—The biotites are common constituents of igneous and metamorphic rocks and pegmatite dikes. They also are common alteration products of certain silicates, such as hornblende and augite. They are present in sedimentary rocks principally as the products of weathering.

Uses.—Phlogopite is used as an insulator in electrical appliances and to a less extent for the same purposes as those for which ground muscovite is employed. No "amber mica" is produced in the United States. Most of that used in this country is imported from Canada.

THE CALCIUM MICAS

Margarite ($Ca(AlO)_2(AlOH)_2(SiO_4)_2$)

Margarite, the calcium mica, is like biotite in the habit of its crystals, which, however, are not so well formed as these. Usually the mineral occurs in tabular plates with hexagonal outlines but without side planes. It occurs also as scaly aggregates.

Analyses of specimens from Gainsville, Ga. (I), and Peekskill, N. Y. (II), gave:

	SiO_2	Al_2O_3	FeO	MgO	CaO	Na_2O	H_2O	Total
I.	31.72	50.03	....	.12	11.57	2.26	4.88	100.58
II.	32.73	46.58	5.12	1.00	11.04	....	4.49	100.96

The mineral has a pearly luster on its basal planes, and a glassy luster on other planes. Its color is white, yellowish, or gray and its streak white. It is transparent or translucent. Its cleavage is not as perfect as in the other micas, and its cleavage plates are less elastic. Its hardness varies from 3 to over 4 and its density is 3. It is a mica of the first order.

Before the blowpipe it swells, but fuses with great difficulty. It gives water in the closed tube and is attacked by acids.

Occurrence.—Margarite is associated with corundum. It is also present in some chlorite schists. In all cases it is of metamorphic origin.

Localities.—It occurs in the Zillerthal, Tyrol; at Campo Longo, in Switzerland; at the emery localities in the Grecian Archipelago; at the emery mines near Chester, Mass.; in schist inclusions in mica diorite at Peekskill, N. Y.; with corundum at Village Green, Penn.; at the Cullakenee Mine, in Clay Co., N. C.; and at corundum localities in Georgia, Alabama and Virginia.

THE LITHIUM-IRON MICAS

Zinnwaldite ($((Li \cdot K \cdot Na)_3FeAl(Al(F \cdot OH))_2Si_5O_{16})$)

The principal lithium-iron mica, zinnwaldite, is a very complex mixture that occurs in several forms so well characterized that they have received different names. All of them contain lithium, iron and fluorine, but in such different proportions that it has not been possible to ascribe to them any one generally acceptable formula. Some of the most important of these varieties have compositions corresponding to the following analyses:

	I	II	III	IV
SiO_2	40.19	59.25	51.46	45.87
Al_2O_3	22.79	12.57	16.22	22.50
Fe_2O_3	19.78	.....	2.21	.66
FeO	.....	.93	7.66	11.61
MnO	2.02	.....	.06	1.75
Na_2O	.....	7.63	.95	.42
K_2O	7.49	5.37	10.65	10.46
Li_2O	3.06	9.04	4.83	3.28
F	3.99	7.32	7.44	7.94
Total	99.32	102.11	102.71	105.48
$-O=F=$	97.64	99.05	99.60	102.15

I. Rabenglimmer from Altenberg, Saxony. Greenish black with greenish gray streak. Sp. gr. = 3.146–3.190.

II. Polylithionite from Kangerluarsuk, Greenland. White or light green plates. Sp. gr. = 2.81.

III. Cryophyllite from Rockport, Mass. Strongly pleochroic green and brownish red crystals. Sp. gr. = 2.909. Contains also .17 MgO and 1.06 H_2O.

IV. Zinnwaldite from Zinnwald, Bohemia. Plates, white, yellow or greenish gray. Sp. gr. = 2.956–2.987. Contains also .91 H_2O and .08 P_2O_5.

Zinnwaldite occurs in crystals with an axial ratio very near that of biotite, and a tabular habit. Twins are like those of biotite with ∞ P(110) the twinning plane.

It has a pearly luster, is of many colors, particularly violet, gray, yellow, brown and dark green and is strongly pleochroic. Its streak is light, its hardness between 2 and 3 and its density between 2.8 and 3.2. It is a mica of the second order.

Before the blowpipe it fuses to a dark, weakly magnetic bead. It is attacked by acids.

Occurrence and Localities.—Zinnwaldite is found in certain ore veins, in granites containing cassiterite, and in pegmatites. Its origin is ascribed to pneumatolytic processes. Its principal occurrences are those referred to in connection with the analyses.

THE ALKALI MICAS

The alkali micas include those in which the principal metallic constituents besides aluminium are lithium, potassium and sodium. All these metals are present in each of the recognized varieties of the alkali micas, but in each variety one of them predominates. That in which lithium is prominent is known as *lepidolite;* that in which potas-

sium is most abundant is *muscovite;* and that in which sodium is most prominent is *paragonite.* Muscovite is common. Lepidolite is abundant in a few places. Paragonite is rare. The first two are important economically. All are micas of the first order, except a few lepidolites, and all are light colored.

Another mica, which is usually regarded as a distinct variety of muscovite, or, at any rate, as being very closely related to the mineral is *roscoelite.* In this, about two-thirds of the Al_2O_3 in muscovite is replaced by V_2O_3. It is a rare green mica which is utilized as an ore of vanadium.

Lepidolite $((Li \cdot K \cdot Na)_2((Al \cdot Fe)OH)_2(SiO_3)_3)$

Lepidolite occurs almost exclusively as aggregates of thin plates with hexagonal outlines. Crystals are so poorly developed that a satisfactory axial ratio has not been determined. Its variation in composition is indicated by the analyses of white and purple varieties from American localities.

	I	II	III	IV
SiO_2	51.52	49.52	51.12	51.25
Al_2O_3	25.96	28.80	22.70	25.62
Fe_2O_3	.31	.40	.80	.12
FeO	undet.	.24	.....	.00
MnO	.20	.07	1.34*	.05
MgO	.02	.02	.....	.00
CaO	.16	.13	.....	tr.
Li_2O	4.90	3.87	5.12	4.31
Na_2O	1.06	.13	2.28	1.94
K_2O	11.01	8.82	10.60	10.65
Rb_2O	.....	3.73	.....	.....
Cs_2O	.....	.08	.....	.....
F	5.80	5.18	6.38	7.06
H_2O	.95	1.72	2.05	1.60
Total (less O=F)	99.45	100.53	99.74	99.63

I. Lilac-purple granular lepidolite from Rumford, Maine.
II. White variety from Norway, Maine.
III. Red-purple variety from Tourmaline Queen Mine, Pala, Cal. Contains also .04 P_2O_5.
IV. White variety from Pala, Cal.

* Mn_2O_3.

The mineral is white, rose or light purple, gray or greenish. The rose and purple varieties contain a little manganese. The streak of all lepidolites is white, their luster pearly, their hardness 2.5–4 and density 2.8–2.9. The refractive indices of a typical variety are: $\beta = 1.5975$, $\gamma = 1.6047$.

Lepidolite fuses easily to a white enamel and at the same time colors the flame red. It is difficultly attacked by acids, but after heating is easily decomposed.

Cookeite from Maine and California is probably a weathered lepidolite. Its analyses correspond to the formula, $Li(Al(OH)_2)_3(SiO_3)_2$.

Occurrence.—The mineral occurs principally in pegmatites in which rubellite (p. 435), and other bright-colored tourmalines exist and on the borders of granite masses and in rocks adjacent to them. It is often zonally intergrown with muscovite. In all cases it is probably a pneumatolytic product, or, at least, is produced by the aid of magmatic emanations.

Localities.—The mineral occurs in nearly all districts producing tin, and also in those producing gem tourmaline. Its best known foreign localities are Jekaterinburg, Russia; Rožna, Moravia; Schnittenhofen, Bohemia; and Penig, Saxony. In the United States it is found in large quantities at Hebron, Paris, and other points in western Maine; in the tin mines of the southern Black Hills, South Dakota, and in the tourmaline localities in the neighborhood of Pala, San Diego Co., Cal.

Uses.—Lepidolite is utilized to a slight extent in the manufacture of lithium compounds, which are employed in the preparation of lithia waters. medicinal compounds, salts used in photography and in the manufacture of fireworks and storage batteries.

Muscovite ($H_2(K \cdot Na)Al_3(SiO_4)_3$)

Muscovite is one of the most common, and at the same time the most important, of the micas. Because of its transparency it is employed for many purposes for which the darker biotite is not suitable.

While predominantly a potash mica, nearly all muscovite contains some soda, due to the isomorphous mixture of the paragonite molecule. Two typical analyses are quoted below:

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	H_2O	F	Total
I.	44.39	35.70	1.09	1.07	tr	...	.10	2.41	9.77	5.88	.72	101.13
II.	46.54	34.96	1.59	....	....	.32	...	.41	10.38	5.43		99.63

I. Broad plates of muscovite bordered by lepidolite, Auburn, Maine.

II. Greenish muscovite, Auburn, Maine. Total less O = F is 100.83.

The crystals are usually tabular and frequently orthorhombic or hexagonal in habit, though the etch figures on their basal planes reveal clearly their monoclinic symmetry (Fig. 194). If orientated to correspond with crystals of biotite their axial constants are: $a : b : c = .5774 : 1 : 3.3128$, $\beta = 89° 54'$, and their principal planes oP(001), ∞P$\bar{\infty}$ (010) $\frac{2}{3}$P$\bar{\infty}$ (023), 4P($\bar{4}$41) and −2P(221) (Fig. 195).

Twins like those of biotite are not uncommon in some localities.

Muscovite is colorless or of some light shade of green, yellow or red. It has a glassy luster, a perfect cleavage parallel to the base, a hardness of 2 and a density of 2.76–3.1. Pleochroism is marked in directions perpendicular and parallel to the cleavage, the color of the crystals, when viewed in the direction perpendicular to the cleavage being lighter

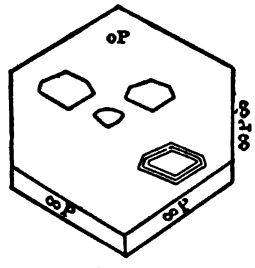


FIG. 194.

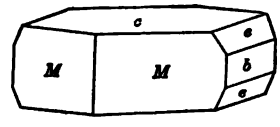


FIG. 195.

FIG. 194.—Etch Figures on oP(001) of Muscovite, Exhibiting Monoclinic Symmetry.
FIG. 195.—Muscovite Crystal with −2P, 221 (*M*); oP, 001 (*c*); ∞P$\bar{\infty}$, 010 (*b*), and $\frac{2}{3}$P$\bar{\infty}$, 023 (*e*).

than when viewed parallel to the cleavage. The optical angle is comparatively large (56°–76°), in this respect being very different from that of biotite which is small (2°–22°). The mineral is a nonconductor of electricity at ordinary temperatures and a poor conductor of heat. Its refractive indices vary somewhat with composition. For yellow light intermediate values are as follows: $\alpha = 1.5619$, $\beta = 1.5947$, $\gamma = 1.6027$.

Before the blowpipe thin flakes of muscovite fuse on their edges to a gray mass. In the closed tube the mineral yields water which, in some cases, reacts for fluorine. It is insoluble in acids under ordinary conditions, but is decomposed on fusion with alkaline carbonates.

Muscovite is very stable under surface conditions. Its principal change is into a partially hydrated substance, which may be called hydromuscovite. It alters also into scaly chloritic products, into steatite (p. 401), and serpentine (p. 398).

Damourite is a dense fine-grained aggregate of muscovite, often forming pseudomorphs after other minerals.

Sericite is a yellowish or greenish muscovite that occurs in thin, curved plates in some schists.

Fuchsite is a chromiferous variety of an emerald-green color from Schwarzenstein, Tyrol.

Synthesis.—Crystals of muscovite have been made by fusing andalusite with potassium fluo-silicate and aluminium fluoride.

Occurrence.—Muscovite occurs in large, ill-defined crystals in pegmatites, and in smaller flakes in granites and other acid igneous rocks, in some sandstones and slates and in various schists and other metamorphic rocks. It is found also in veins. It is in some cases an original pyrogenic mineral, in other cases a metamorphic mineral and in still other cases a secondary mineral resulting from the alteration of alkaline aluminous silicates.

Localities.—The mineral occurs in all regions where pegmatites and acid igneous rocks exist. It is mined in North Carolina, South Dakota, New Hampshire, Virginia and other states. While phlogopite (amber mica) is produced in some countries all the mica produced in this country is of the muscovite variety.

Uses.—Muscovite is used in two forms, (1) as sheet mica, and (2) as ground mica. The sheet mica comprises thin cleavage plates cut into shapes. It is used in making gas-lamp chimneys, lamp shades, and windows in stoves. The greater portion is used as insulators in electrical appliances, though for some forms of electrical apparatus the amber mica is better. Because of the comparatively high cost of large mica plates, small plates are sometimes built up into larger ones. The ground mica consists of small crystals and the waste from the manufacture of sheet mica ground very fine. It is used in the manufacture of wall paper, heavy lubricants and fancy paints. It is also mixed with shellac and melted into desired forms for electrical insulators.

Production.—The total value of the mica produced in the United States during 1912 was $355,804, divided as follows: 1,887,201 lb. sheet mica, valued at $310,254 and 3,512 tons ground mica, valued at $45,550. Of this North Carolina produced 454,653 lb. of sheet mica, valued at $187,501 and 2,347 tons of scrap mica, valued at $29,798, or a total value for both kinds of mica of $217,299. The imports of sheet mica during the same year amounted to $502,163, of which 241,124 lb., valued at $155,686 was trimmed and the balance untrimmed. The imports during 1912 were valued at $748,973, and the domestic production at $331,896.

Roscoelite may be regarded as a muscovite in which a large portion of the Al_2O_3 has been replaced by V_2O_3. A specimen from Lotus, Eldorado Co., Cal., gave:

SiO_2	TiO_2	Al_2O_3	V_2O_3	FeO	MgO	K_2O	H_2O-	H_2O+	Total
45.17	.78	11.54	24.01	1.60	1.64	10.37	.40	4.29	99.80

besides traces of Li_2O and Na_2O.

The mineral occurs as clove-brown or green scales with a specific gravity of 2.92–2.94. It is translucent and has a pearly luster and a strong pleochroism. Its refractive indices for sodium light are: $\alpha = 1.610$, $\beta = 1.685$, $\gamma = 1.704$.

Before the blowpipe it fuses to a black glass. It gives the usual reactions for vanadium in the beads and is only slightly affected by acids. It has been found associated with gold in small veins near Lotus, Eldorado Co., California, in seams composed of roscoelite and quartz between the beds of a sandstone in the high plateau region of southwestern Colorado, and as a cement of minute scales between the grains of the sandstone on both sides of the seams. In all cases it appears to have been deposited by percolating water, possibly of magmatic origin.

The impregnated sandstone is mined as a source of vanadium. The material, which contains an average of about 3 per cent of metallic vanadium is concentrated by chemical processes, and the concentrates are manufactured into ferro-vanadium. Most of the vanadium produced in the United States is made from this ore.

Paragonite ($H_2(Na \cdot K)Al_3(SiO_4)_3$)

Paragonite, the sodium mica, differs from muscovite mainly in composition. Both contain sodium and potassium but in paragonite the sodium molecule is in excess.

The analysis quoted below is made on a sample from Monte Campione, in Switzerland.

SiO_2	Al_2O_3	Fe_2O_3	Na_2O	K_2O	H_2O	Total
47.75	40.10	tr.	6.04	1.12	4.58	99.59

It occurs in the same associations as some forms of muscovite but it is much less common. It apparently occurs most abundantly in certain fine-grained mica schists to which the name paragonite schists has been given. It is in all known cases a product of dynamic metamorphism.

CHAPTER XVII

THE SILICATES—*Continued*

THE ANHYDROUS METASILICATES

NORMAL METASILICATES

Beryl ($Be_3Al_2(SiO_3)_6$)

BERYL is a frequent constituent of coarse-grained granites. It is important as a gem material, and is particularly interesting because of the many physical investigations that have been made with the aid of its crystals.

Although the mineral is essentially a beryllium alumino-metasilicate, it usually contains also a little Fe_2O_3 and MgO, in many cases small quantities of the alkalies, and in some cases also cæsium. Analyses of a green beryl from North Carolina, an aquamarine from Stoneham, Me., and a light-colored crystal from Hebron are given below.

	SiO_2	Al_2O_3	Fe_2O_3	BeO	FeO	Na_2O	Li_2O	Cs_2O	H_2O	Total
I.	66.84	19.05	...	14.11	...	....	....	....	....	100.00
II.	66.28	18.60	...	13.61	.22	....	....	....	.83	99.54
III.	65.54	17.75	.21	13.73	...	.71	....	....	2.01	100.39
IV.	62.44	17.74	.40	11.36	.38	1.13	1.60	3.60	2.03	100.30

I. Theoretical.
II. Alexander Co., N. C.
III. Stoneham, Me.; also .06% CaO.
IV. Hebron, Me.

The mineral occurs massive without distinct crystal form and also in granular and columnar aggregates, but its usual method of occurrence is in sharp and, in some cases, very large columnar crystals with a distinct hexagonal habit (dihexagonal bipyramidal class), and an axial ratio 1 : .4989. The forms found on nearly all crystals are $\infty P(10\bar{1}0)$, $\infty P2(11\bar{2}0)$, $oP(0001)$, $P(10\bar{1}1)$, $P2(11\bar{2}2)$ and $2P2(11\bar{2}1)$ (Fig. 196). In addition, there are present on many crystals other prismatic forms and the pyramids $3P\frac{3}{2}(21\bar{3}1)$ and $2P(20\bar{2}1)$. Other crystals are highly

modified (Fig. 197), the total number of forms that have been identified approximating 50. The angle $10\bar{1}1 \wedge 01\bar{1}1 = 28° \ 55'$. Some crystals are very large, measuring 2 to 4 feet in length and 1 ft. in diameter.

Beryl has a glassy luster. It is transparent or translucent. It is colorless or of some light shade of green, red, or blue. Its streak is white, hardness 7–8 and density 2.6–2.8. Its cleavage is very imperfect but there is frequently a parting parallel to the base. Pleochroism is noticeable in green and blue crystals. Its refractive indices for yellow light at 20° are: $\omega = 1.5740$, $\epsilon = 1.5690$. They become greater with increasing temperature.

Before the blowpipe colorless varieties become milky, but others are

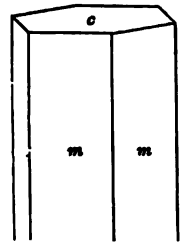
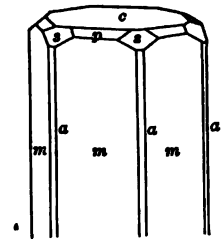


FIG. 196.



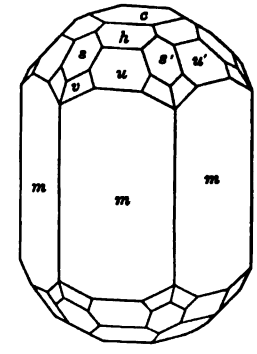


FIG. 197.

FIG. 196.—Beryl Crystals with ∞P, $10\bar{1}0$ (*m*); $0P$. 0001 (*c*); $\infty P2$, $11\bar{2}0$ (*a*); P, $10\bar{1}1$ (*p*) and $2P2$, $11\bar{2}1$ (*s*).

FIG. 197.—Beryl Crystal with *m*, *c*, *p* and *s* as in Fig. 196. Also 2P, $20\bar{2}1$ (μ) and $3P\frac{3}{2}$, $21\bar{3}1$ (*v*).

unchanged except at very high temperatures when sharp edges are fused to a porous glass. The mineral is not attacked by acids.

Beryl is distinguished from *apatite*, which it much resembles, by its greater hardness.

It alters to mica and kaolin (p. 404).

Syntheses.—Beryl crystals have been formed by long heating of SiO_2, Al_2O_3 and BeO in a melt of the molybdate or vanadate of lithium, and by precipitating a solution of beryllium and aluminium sulphates with sodium silicate and heating the dried precipitate with boric acid in a porcelain oven.

Occurrence.—The mineral occurs as an accessory constituent in pegmatites and granites, in crystalline schists, especially mica schists and

gneisses, in ore veins and sometimes in clay slates and bituminous limestones.

Uses.—The transparent varieties are utilized as gems, under the following names:

Emerald is a deep green variety, the color of which is probably due to Cr_2O_3,

Aquamarine, a blue-green variety,

Golden beryl, a topaz-colored variety,

Blue beryl, a blue variety, and

White beryl, a colorless variety.

Localities.—Crystals of ordinary beryl occur at Striegau, Silesia; in the cassiterite veins near Altenberg, in Saxony; in the granite dikes near S. Piero, Elba; in the Mourne Mts., at Down, Ireland; at various points (especially near Jekaterinburg), in Ural, Russia, and in North America, in the mountain counties of North Carolina; at Mt. Antero, Colo.; at Peiperville, Penn.; in granite veins at Haddam, Conn., at Acworth, N. H., and at Norway, Hebron, and other points in western Maine. Much of the beryl of Maine is the variety containing cæsium.

The finest emeralds are found in geodes, and embedded in a clay slate at the Muso Mine, Colombia, New Grenada; but fine gem material occurs also at Zabara, near the Red Sea; Habachthal, Tyrol; Glen, New South Wales, and in Brazil, Hindustan and Ceylon. The finest aquamarines come from Siberia.

The most important beryl mines in the United States are in pegmatites in Cleveland, Burke and Macon Counties, N. C. Aquamarine, golden beryl and the more usual varieties occur at Walker Knob, Burke Co., and on Whiterock Mt. in Macon Co., but those at the first-named locality are not clear enough to furnish gems. Near Clayton, Ga., a pegmatite contains large bluish and yellowish green beryls, some of which yield gem material. The finest aquamarine ever found in the United States was from Stoneham, Me. Near Shelby, Cleveland Co., and at Crabtree Mountain, Mitchell Co., in North Carolina, genuine emeralds occur in a pegmatite that cuts basic rocks. Fine emeralds have also been mined at Stony Point, N. C., Haddam, Conn., and Topsham, Me.

Production.—The total yield of emerald from North Carolina during 1912 was about 2,969 carats, valued at $12,875 in the rough. The average value of the cut stone was $25 per carat, but some especially fine gems from the Shelby locality were valued at $200 per carat. There were also produced in the United States during this year other varieties of beryl, valued at $1,765.

Leucite ($K_2Al_2(SiO_3)_4$)

Leucite occurs almost exclusively in what are apparently simple isometric crystals, but which are actually polysynthetic twins of a doubly refracting substance. At 500° and above, leucite substance is isometric. It separates from molten magmas as isometric crystals, which, upon further cooling, become twinned. The twinning is revealed by striation on the crystal faces. The substance is, therefore, dimorphous.

Theoretically, leucite is a potassium aluminium metasilicate, but most natural crystals contain some soda and many contain small quantities of calcium. The calculated composition of the pure molecule and the actual composition of two natural crystals are shown below.

	SiO_2	Al_2O_3	CaO	Na_2O	K_2O	H_2O	Total
Calculated.....	55.02	23.40	....	....	21.58	...	100.00
Mt. Vesuvius..	55.28	24.08	....	.60	20.79	...	100.75
Mt. Vulture....	54.94	25.10	1.80	1.23	15.18	2.13	100.38

The mineral occurs in icositetrahedrons, 2O2(211), in some cases modified by ∞O(110) and ∞O∞(100). Twinning parallel to ∞O(110) is common, but often the twins are polysynthetic and are recognizable only by striations on the crystal faces. The twinning lamellae are anisotropic, as shown by their optical properties, but at 500° the twinning disappears and the crystals become completely isotropic throughout.

Leucite is glassy in luster and colorless, white or light gray in color. It is transparent or translucent and has a white streak. Its cleavage is imperfect parallel to ∞O(110), and its fracture is conchoidal or uneven. It is brittle. Its hardness is 5–6 and density 2.5. Its indices of refraction approximate 1.508.

Before the blowpipe leucite is infusible. It is soluble in HCl with the production of pulverulent silica. Its powder reacts strongly alkaline.

It is distinguished from other minerals by its crystallization, by the violet color it imparts to the flame and its reaction toward HCl. It is most apt to be confused with *analcite* (p. 458) and colorless *garnet*. It is distinguished from the latter by its inferior hardness and from the former by its infusibility and failure to yield water when heated in the glass tube below red heat. Analcite, moreover, fails to give the flame test for potash.

The mineral alters quite readily into analcite and some other zeolite, into a mixture of orthoclase and nepheline, or into orthoclase (p. 413)

and muscovite, or into orthoclase alone. Its final alteration product is kaolin.

Syntheses.—Its crystals have been obtained by fusing its constituents, and also by melting a mixture of SiO_2, potassium aluminate and vanadate, and by fusing a mixture of SiO_2 and Al_2O_3 with an excess of KF.

Occurrence.—It occurs only in igneous rocks, especially in lavas low in silica and high in potash, and in the plutonic rock known as missourite. In some old rocks it is represented by its alteration products. In all cases it is a primary mineral.

Localities.—Leucite is an essential constituent of the lavas in the Kaiserstuhl, Baden; in Rhenish Prussia; near Wiesenthal, Saxony; in the Siebenburger, Bohemia; at Vesuvius, Italy; in the Leucite Hills, and other places in Wyoming, and at several places in Montana; at Magnet Cove, Ark., and near Hamburg, N. J.

Uses.—It is suggested that the large masses of leucite rocks in the Leucite Hills be used as a source of potash. On the assumption that the rocks at this place contain 10 per cent of K_2O it is estimated that the total quantity of potash in them amounts to about 200,000,000 tons.

THE AMPHIBOLOIDS

The amphiboloids embrace a large number of minerals, some of which are extremely important as rock components. Economically,

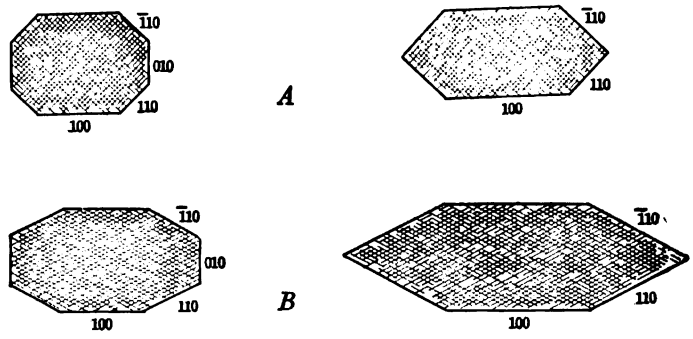


FIG. 198.—Cross-Sections of Pyroxene (*A*) and Amphibole (*B*) Crystals Illustrating Differences in Intersections of Cleavages.

they have little value. Several are used in the arts, but only to a comparatively slight extent. Apparently they crystallize in the orthorhombic, monoclinic and triclinic systems.

The amphiboloids are divisible into two groups, the *pyroxenes* and the *amphiboles*, which differ from one another in the ratio between their

a and *b* axes. In the pyroxenes this ratio is nearly 1 . 1, while in the amphiboles it is approximately 2 : 1. The angle between the prismatic planes (∞P, 110) on the former is nearly equal (87° and 93°), and on the latter very unequal (56°–124°). Since, moreover, in all members of both groups there is a distinct cleavage parallel to the unit prism, the angles of intersection of the cleavage planes in the pyroxenes and in the hornblendes are also different. This difference in prismatic and cleavage angles of the two groups serves readily to distinguish between them (Fig. 198).

The pyroxenes appear to be the more stable at high temperatures and the amphiboles under high pressures. Thus pyroxenes are more common than the amphiboles in lavas and amphiboles more common than pyroxenes in crystalline schists.

Chemically, the amphiboloids are metasilicates of Na, Li, Mg, Ca, Fe, Mn, Zn and Al, or isomorphous mixtures of these metasilicates with one another and with an orthosilicate of the general composition represented by $(Mg \cdot Fe)((Al \cdot Fe)O)_2SiO_4$.

THE PYROXENES

$(R''SiO_3,\ R'Al(SiO_3)_2$ and $R''(R'''O)_2SiO_4)$

The pyroxenes occur very widely spread as constituents of igneous rocks, and in veins that have been filled by igneous processes. Some members of the group are also common metamorphic products. Although crystallizing in different systems their crystals possess a certain family resemblance, expressed best in their horizontal cross-sections, which have a nearly orthorhombic symmetry, i.e., they are nearly symmetrical about two planes at right angles to one another, passing through the *a* and *b* axes, which are nearly equal. The most perfect cleavage of all the pyroxenes is parallel to ∞P(110), and consequently their cleavage angles are nearly equal (Fig. 198A). They approximate 92° and 88°, with the plane of the *a* and *c* axes (the plane of symmetry in monoclinic forms) bisecting the acute angle.

The best known members of the series with their axial ratios are listed below. In the case of the orthorhombic members it will be noticed that the shorter of the lateral axes is made 1. This is done to emphasize the correspondence between the orthorhombic, monoclinic and triclinic forms in their axial ratios. The usual orientation, that which regards the longer of the lateral axes as $b(=1)$ gives $a : b : c = .9702 : 1 : .5710$ for bronzite, and $.9713 : 1 : .5700$ for hypersthene. By many authors wollastonite and pectolite are placed in an independent

group partly because of the fact that they are much more easily decomposed by acids than are the other pyroxenes, and partly because of their very different crystal habits, and different axial ratios.

Orthorhombic (possibly twinned monoclinic).

Enstatite	$MgSiO_3$	$b : a : c$	$= 1.035 : 1 : .587$	
Bronzite	$(Mg \cdot Fe)SiO_3$		$= 1.0308 : 1 : .5885$	
Hypersthene	$FeSiO_3$		$= 1.0295 : 1 : .5868$	

Monoclinic (monoclinic prismatic class).

Wollastonite	$CaSiO_3$	$a : b : c$	$= 1.0523 : 1 : .9649$	$\beta = 84° 35'$
Pectolite	$HNaCa_2(SiO_3)_3$		$= 1.1140 : 1 : .9864$	$= 84° 40'$
Diopside	$(Mg \cdot Ca)SiO_3$		$= 1.0921 : 1 : .5893$	$= 74° 11'$
Sahlite	$(Mg \cdot Fe)Ca(SiO_3)_2$			
Hedenbergite	$FeCa(SiO_3)_2$		$= 1.090 : 1 : .583$	$= 74° 10'$
Schefferite	$(Mg \cdot Fe)(Ca \cdot Mn)(SiO_3)_2$			
Augite	$\left\{ \begin{array}{l} (Mg \cdot Fe)Ca(SiO_3)_2 \\ (Mg \cdot Fe)((Al \cdot Fe)O)_2SiO_4 \\ Na(Al \cdot Fe)(SiO_3)_2 \end{array} \right\}$		$= 1.0955 : 1 : .5904$	$= 74° 14'$
Acmite	$NaFe(SiO_3)_2$		$= 1.0996 : 1 : .6012$	$= 73° 11'$
Aegirine	$\left\{ \begin{array}{l} NaFe(SiO_3)_2 \\ (Mg \cdot Fe)((Al \cdot Fe)O)_2SiO_4 \end{array} \right\}$		$= 1.098 : 1 : .601$	$= 73° 09'$
Jadeite	$NaAl(SiO_3)_2$		$= 1.103 : 1 : .613$	$= 72° 45'$
Spodumene	$LiAl(SiO_3)_2$		$= 1.1283 : 1 : .6234$	$= 69° 33'$

Triclinic (triclinic pinacoidal class).

Rhodonite	$MnSiO_3$	$a : b : c$	$= 1.0729 : 1 : .6213$	$\beta = 108° 44'$
Bustamite	$(Mn \cdot Ca)SiO_3$			
Babingtonite	$(Ca \cdot Fe \cdot Mn)_2Fe_2(SiO_3)_6$		$= 1.0807 : 1 : .6237$	$\beta = 108° 34'$
Fowlerite	$(Mn \cdot Fe \cdot Ca \cdot Zn)SiO_3$			

In addition, there are several comparatively rare monoclinic pyroxenes and one triclinic form, that contain zirconium. They occur only as components of rocks rich in alkalies.

ORTHORHOMBIC PYROXENES

Enstatite ($MgSiO_3$)—Bronzite—Hypersthene ($FeSiO_3$)

The orthorhombic pyroxenes are isomorphous mixtures of $MgSiO_3$ and $FeSiO_3$. The pure magnesium and iron molecules are not known in nature, though the former has been produced artificially. Nearly all members of the group contain both magnesium and iron. When the proportion of the iron present is small (5 per cent FeO), the mixture is known as *enstatite*. Mixtures with 5 to 16.8 per cent of FeO (cor-

responding to MgO : FeO = 3 : 1), are known as *bronzite* and mixtures containing more than 16.8 per cent FeO are known as *hypersthene*. The composition of $MgSiO_3$ and of some typical members of the group follow.

	SiO_2	Al_2O_3	FeO	MgO	CaO	H_2O	Total
I.	60.03	....	.....	39.97	....	...	100.00
II.	58.00	1.35	3.16	36.91	....	.80	100.22
III.	55.50	....	16.80	27.70	....	...	100.00
IV.	52.12	1.69	20.94	21.56	3.20	...	99.51

I. Calculated composition of $MgSiO_3$.
II. Portion of large crystals of enstatite from Kjorrestad, Norway.
III. Calculated composition of upper limit of bronzite, i.e., in which MgO : FeO = 3 : 1.
IV. Hypersthene powder separated from a gabbro at Mt. Hope, Md.

The three minerals occur in crystals that have a well marked orthorhombic symmetry, but it is believed that this may be a case of pseudosymmetry only, i.e., that the minerals may in reality be monoclinic, and that their apparently orthorhombic symmetry may be due to repeated polysynthetic twinning of very thin lamellae. Monoclinic $MgSiO_3$ has been made by fusion of SiO_2 and MgO in the presence of B_2O_3, but it is not certain that this is identical with an iron-free enstatite.

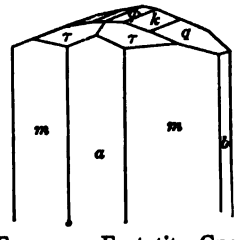


FIG. 199.—Enstatite Crystal with ∞P, 110 (*m*); ∞P$\bar{\infty}$, 100 (*a*); ∞P$\breve{\infty}$, 010 (*b*); $\frac{2}{3}$P$\breve{\infty}$, 023 (*q*); $\frac{1}{2}$P$\breve{\infty}$, 012 (*k*); $\frac{1}{6}$P$\breve{\infty}$, 016 (*φ*) and $\frac{2}{3}$P, 223 (*τ*).

The natural crystals of the orthorhombic pyroxenes are columnar in habit and are usually bounded by ∞P(110), ∞P$\bar{\infty}$ (010), ∞P$\bar{\infty}$ (100), P$\bar{2}$(212), $\frac{1}{4}$P$\breve{\infty}$ (014), with the addition on some crystals of ∞P$\breve{2}$(120), $\frac{3}{4}$P$\breve{\infty}$ (034), P(111), 2P$\bar{2}$(211), $\frac{1}{2}$P$\breve{\infty}$ (012) and other forms (Fig. 199). All cleave perfectly parallel to ∞P(110) with a cleavage angle of 88° 16′–20′ and 91° 40′–44′. The angle 110 ∧ 1$\bar{1}$0 = 88° 16′ to 88° 20′.

The color and other physical properties of the orthorhombic pyroxenes vary with the amount of iron present. Enstatite is light gray, yellow or green. Hypersthene is black, dark purple or dark green. Bronzite is brown, or some shade lighter than hypersthene and darker than enstatite. All colored varieties are pleochroic, the difference in color in different directions increasing with the increase in iron. Green, red, yellow and brown tints are most prominent. All varieties have a colorless streak.

Many hypersthenes and bronzites exhibit a metallic shimmer on $\infty P \bar{\infty}$ (010), due to tiny inclusions with their flat sides parallel to this direction. The hardness of the orthorhombic pyroxenes varies between 5 and 6 and their density between 3.1 and 3.5 increasing with the iron present. Their refractive indices for yellow light are:

Enstatite.....	$\alpha = 1.665$	$\beta = 1.669$	$\gamma = 1.674$
Hypersthene.....	$= 1.692$	$= 1.702$	$= 1.705$

Before the blowpipe the iron-free members of the series are infusible. With increase in iron they become more easily fusible, very ferruginous hypersthene melting easily to a greenish black weakly magnetic glass. When treated with hydrochloric acid the members near enstatite are unattacked, while those near hypersthene are slightly decomposed.

Syntheses.—Crystals of these pyroxenes have been made by fusing the proper components with B_2O_3, and by heating mixtures of SiO_2 and $MgCl_2$. They are frequent constituents of slags.

Occurrence.—The rhombic pyroxenes occur in igneous rocks, in crystalline schists, in metamorphosed dolomites and in veins that have been filled by igneous magmas. They are not very stable under the conditions at the earth's surface. They weather to serpentine, hornblende and rarely to talc. Enstatite occurs also in meteorites.

Localities.—Good crystals of the orthorhombic pyroxenes are found in the volcanic bombs (inclusions in lava) of the Lake Laach district, Prussia; in ore veins at Bodenmais, Bavaria; at Málnás, Hungary; in the trachyte of Mont Doré, France; in apatite veins at Snarum, Norway; and in a glassy andesite on Peel Island, Japan. In the United States they occur in basic coarse-grained igneous rocks in North Carolina, Maryland, and the Highlands of New York and New Jersey, in volcanic rocks in Colorado, and at the Corundum Mines, in Georgia. Especially fine bronzite occurs on Paul's Island, Labrador.

MONOCLINIC PYROXENES

The monoclinic pyroxenes comprise a series of isomorphous mixtures of monoclinic metasilicates of Na, Li, Ca, Mg, Fe″ and Mn and the silicate $R''(R'''O)_2SiO_4$, in which R″ is usually Mg, Ca or Fe and R‴ is Al or Fe.

Although their chemical composition varies quite widely, the crystallization of all the members of the group is practically the same. With the exception of *wollastonite* and *pectolite* the habit of their crystals is similar and their corresponding interfacial angles have approximately the same value.

The group may be subdivided into four subgroups (1) the wollastonite subgroup, including this mineral and pectolite, with calcium as the principal metallic component, (2) the magnesium-calcium-iron pyroxenes, including *diopside*, *salite*, *kelenbergite* and *augite*, and (3) the alkali pyroxenes including *acmite*, *jadeite* and *spodumene*. A fourth subgroup includes the rare zirconium-bearing pyroxenes. All crystallize in the monoclinic prismatic class.

Wollastonite Subgroup

These minerals, because their axial ratios are somewhat different from those of the other monoclinic pyroxenes, and because they are much more easily decomposed by acids, are by some mineralogists regarded as constituting an independent group.

Wollastonite ($CaSiO_3$)

Wollastonite analyses correspond very closely to the theoretical composition required by the formula assigned to it. There is, however, nearly always a little Fe_2O_3 present and usually there are present also small traces of other constituents. A dimorph, pseudowollastonite, or β wollastonite, has been made by melting wollastonite and cooling slowly, but it has not yet been found in nature. Its crystals are hexagonal or monoclinic with an hexagonal habit.

	SiO_2	FeO·MnO	CaO	MgO	Na_2O	H_2O	Total
Theoretical.....	51.75	...	48.25	...	...	...	100.00
Bonaparte Lake, N. Y.	50.66	.07	47.98	.05	.46	.72	99.94

The mineral forms tabular or columnar crystals bounded by $\infty P\bar{\infty}$ (100), $-P\bar{\infty}$ (101), oP(001), $P\bar{\infty}$ ($10\bar{1}$), $\infty P\bar{2}$(120), $-P\bar{2}$($12\bar{2}$) and $\infty P\frac{5}{4}$(540) (Fig. 200). Twins are sometimes found with $\infty P\bar{\infty}$ (100) the twinning plane. The angle $540 \wedge 5\bar{4}0 = 79°$ 58′. The mineral occurs also in granular and fibrous masses. Its cleavage is perfect parallel to $\infty P\bar{\infty}$ (100) and only a little less perfect parallel to oP(001).

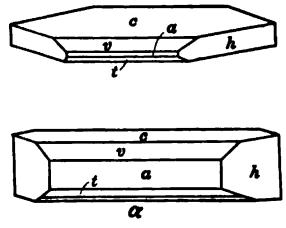


FIG. 200.—Wollastonite Crystal with oP, 001 (*c*); $\infty P\bar{\infty}$, 100 (*a*); $-P\bar{\infty}$, 101 (*v*); $+P\bar{\infty}$, $\bar{1}01$ (*t*); $+\frac{1}{2}P\bar{\infty}$, $\bar{1}02$ (*α*) and $\infty P\frac{5}{4}$, 540 (*h*).

Wollastonite is usually colorless or white, but in some cases is grayish, yellowish, reddish or brown. It is transparent or translucent and has a white streak. Its luster is glassy except on the cleavage face where it is often pearly. Its hardness is

4.5–5 and density 2.8–2.9, and its refractive indices for yellow light are: $\alpha = 1.621$, $\beta = 1.633$, $\gamma = 1.636$.

Before the blowpipe wollastonite fuses with difficulty to a white transparent glass. Its fusing point varies between 1240° and 1325°, diminishing with increase in iron. It dissolves in HCl, leaving a residue of gelatinous silica, and is attacked vigorously by strong solutions of NaOH. When fused it recrystallizes in hexagonal crystals (pseudo-wollastonite).

The mineral is distinguished from other white silicates by its crystallization, its cleavage and its solubility in hydrochloric acid. Its principal alteration is into apophyllite (p. 443).

Syntheses.—Crystals of wollastonite have been made by fusing SiO_2 and CaF_2, and by dissolving the hexagonal modification (made by fusing and cooling wollastonite) in molten calcium vanadate at 800°–900°.

Occurrence.—Wollastonite is characteristically a product of metamorphic processes, both contact and regional. It occurs in metamorphosed dolomites, in the limestone inclusions in the lava of Vesuvius, etc., in many gneisses and in some eruptive rocks. It is found also abundantly in calcareous slags.

Localities.—Crystals of wollastonite are found in the phonolite of the Kaiserstuhl, near Freiburg, Bavaria; in a contact metamorphosed limestone near Cziklova, Hungary; in the limestone bombs in the lava of Mt. Somma, Naples, Italy, and of Santorin, Greece; and in limestone at Diana, N. Y. Granular or fibrous masses occur also at Attleboro, Penn., at different points in Lewis, Essex and Warren Counties, N. Y.; and at the Cliff Mine, Keweenaw Pt., Mich.

Pectolite ($HNaCa_2(SiO_3)_3$)

Pectolite was formerly regarded as a partially weathered wollastonite. Recent analyses, however, indicate that it may have a definite composition which can be represented by the formula written above, as shown by the analyses quoted below. The excess of water shown by most analyses is ascribed to the admixture of some weathered material.

	SiO_2	Al_2O_3	MgO	CaO	Na_2O	K_2O	H_2O	Total
I.	54.23	.....	....	33.72	9.34	...	2.71	100.00
II.	45.32	.....	....	34.00	9.32	...	2.55	100.30
III.	53.94	.71	1.43	32.21	8.57	.47	4.09	100.82

I. Theoretical.
II. Niakornat, Greenland. Contains also .11 per cent Fe_2O_3.
III. Point Barrow, Alaska.

The mineral usually occurs in fibrous masses of acicular crystals elongated in the direction of the orthoaxis, but in a few cases in tabular forms flattened parallel to $\infty P \bar{\infty}$ (100). Its cleavage is distinct parallel to the same plane.

Pectolite when pure, or nearly pure, is colorless or white or gray, and transparent or translucent. Its luster is pearly on cleavage surfaces and satiny on fracture surfaces. Its hardness is about 4.5 and its density 2.88. When broken in the dark, some specimens phosphoresce. Its average refractive index for yellow light is 1.61.

Before the blowpipe the mineral fuses to a white enamel. It yields water when heated in the closed tube and when treated with hot hydrochloric acid it decomposes, leaving a residue of flocculent silica.

The principal alteration product of pectolite is talc (p. 401).

Synthesis.—Small, fine needles of pectolite have been produced by heating to 400° mixtures of SiO_2, Al_2O_3, Na_2O, CaO and H_2O, in various proportions.

Occurrence.—The mineral occurs in druses and as isolated crystals on the walls of cracks in eruptive rocks, and also in a few instances as vein fillings, and as a constituent of metamorphic rocks. It is mainly a secondary mineral.

Localities.—Crystals are found in seams in basalts at Edinburghshire, Scotland; at Bergen Hill, N. J., in clefts in traprock; and in the eleolite-syenite at Magnet Cove, Ark. (*manganopectolite* with about 4 per cent MnO). At Barrow Point, Alaska, fine-grained fibrous aggregates are found in abandoned workshops of the Eskimo. Radially fibrous masses occur in the Thunder Bay region, Lake Superior, at Disco, Greenland, and at a number of points in the Alps.

Magnesium-Calcium-Iron Pyroxenes

Diopside-Augite

The calcium-magnesium-iron pyroxenes include a number of compounds that have been given distinctive names. They are apparently isomorphous mixtures of the metasilicates of Mg, Ca, Fe and Mn, or of these together with the magnesium and iron salts of the basic orthosilicate of iron and aluminium $(Mg \cdot Fe)((Al \cdot Fe)O)_2SiO_4$.

The crystals of all members of the group are alike in habit and similar in their interfacial angles. Their axial ratios are nearly the same and the angle β has nearly the same value in all. It is possible that the slight differences observed are due to the effect of the varying amounts of iron present. The crystals are nearly all short columnar in habit, with

the vertical zone well developed. The simplest crystals are bounded by $\infty P\bar{\infty}$ (100), ∞P(110), $\infty P\breve{\infty}$ (010) and P($\bar{1}$11), but $-$P(111), 2P($\bar{2}$21), oP(001) and 2P$\breve{\infty}$ (021) are also common (Fig. 201). Other forms to the number of 95 have been observed, but they are comparatively rare. Contact and interpenetration twins are fairly common. In the contact twins the usual twinning plane is $\infty P\bar{\infty}$ (100) (Fig. 202). Polysynthetic twins are twinned parallel to oP(001). In the interpenetration twins $-P\bar{\infty}$ (101) (Fig. 203) and P2($\bar{1}$22) are the twinning planes. The cleavage is parallel to ∞P(110), the cleavage angles being about 93° and 87°. Partings are also common, parallel to one or the other of the three pinacoids.

All the pyroxenes of this group have a glassy luster and are transparent or translucent. Their color varies with composition as does also

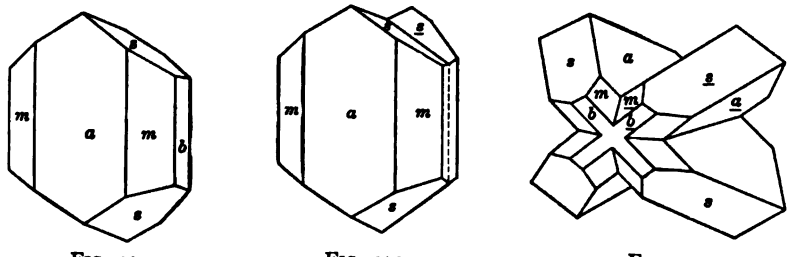


FIG. 201. FIG. 202. FIG. 203.

FIG. 201.—Augite Crystal with ∞P, 110 (*m*); $\infty P\bar{\infty}$, 100 (*a*); $\infty P\breve{\infty}$, 010 (*b*) and P, $\bar{1}$11 (*s*).

FIG. 202.—Augite Twinned about $\infty P\bar{\infty}$ (100).

FIG. 203.—Interpenetration Twin of Augite, with $-P\bar{\infty}$ (101) the Twinning Plane.

their hardness and density. The limits of hardness are 5 and 6 and of density 3.2 and 3.6. The streak of all varieties is white. Pleochroism has been observed in some occurrences but it is not as noticeable as in the corresponding amphiboles. In the pyroxenes of this group it is usually in shades of green, but in the diallage of the Lake Superior region it is fairly strong in shades of amethyst.

Before the blowpipe the members of the group are fusible, their fusibility increasing with the quantity of iron present. The fusing temperature of the pure diopside is 1381° and of hedenbergite 1100°–1160°. The fusing points of the other pyroxenes of the group lie between these temperatures. None of the varieties are attacked by acids to any appreciable degree.

All the pyroxenes are distinguished from other minerals by their crystallization and their cleavage.

Diopside is a mixture of the magnesium and calcium silicates in which the two molecules are in the ratio 1 : 1. With the addition of the corresponding iron molecule diopside grades into sahlite. The calculated composition of a mixture of the formula $MgCa(SiO_3)_2$ is indicated in the first line. The compositions of several typical diopsides are quoted in the following two lines.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Total
Theoretical.....	55.55	...	...	....	18.52	25.93	100.00
Albrechtsberg, Aus...	55.60	.16	...	.56	18.34	26.77	101.43
Alathal, Switzerland.	54.28	.51	.98	1.91	17.30	25.04	100.02

Its crystals are usually characterized by the presence of the basal plane (Fig. 204). The value of the angle $110 \wedge 1\bar{1}0 = 92° 50'$.

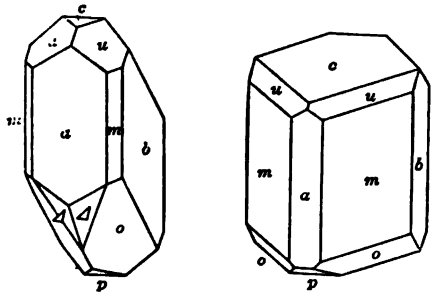


FIG. 204.—Diopside Crystals with ∞P, 110 (*m*); ∞P$\bar{\infty}$, 100 (*a*); ∞P$\breve{\infty}$, 010 (*b*); oP, 001 (*c*), −P, 111 (*u*); +2P, $\bar{2}21$ (*o*); 3P$\bar{3}$, $\bar{3}11$ (Δ); +P$\bar{\infty}$, $\bar{1}01$ (*p*).

Diopside is usually light green or colorless, yellowish, dark green or nearly black and rarely deep blue. The lighter varieties are transparent or translucent, the darker ones opaque. The density of the pure mineral is 3.25. Its refractive indices for yellow light are: $\alpha = 1.6685$, $\beta = 1.6755$, $\gamma = 1.6980$. All these values increase with increase in the iron molecule. Among the varieties that have been given distinct names may be mentioned:

Malacolite, a pale colored translucent variety, and

Chrome-diopside, a bright green variety containing from one to several per cent Cr_2O_3.

Diopside occurs in igneous rocks and in metamorphosed limestones.

Hedenbergite is the calcium-iron pyroxene, though it always contains some of the diopside molecule. The calculated compositions of the type mineral ($FeCaS_2O_6$) and of a specimen from its best known locality are:

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Total
Theoretical.....	48.39	....	...	29.43	....	22.18	100.00
Tunaberg, Sweden..	47.62	1.88	.10	26.29	2.76	21.53	100.18

The mineral is black, except varieties that contain Mn which are grayish green. It occurs in crystals (Fig. 205) and in lamellar masses. Its density is 3.31, and refractive indices for yellow light, $\alpha = 1.7320$, $\beta = 1.7366$, $\gamma = 1.7506$.

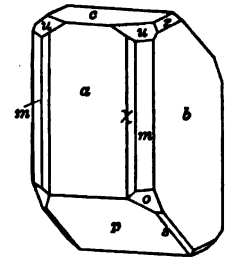


FIG. 205.—Hedenbergite Crystal. Forms *a*, *m*, *b*, *c*, *o*, *p*, *u* and *s* as in Fig. 204. Also 2P $\bar{\infty}$, 021 (*z*) and $\infty P\bar{5}$, 510 (*x*).

Sahlite.—Intermediate between diopside and hedenbergite are several pyroxenes which are characterized by possessing all three of the elements Ca, Mg and Fe in notable amounts. Of these the most common is sahlite, which is grayish, grayish green or black. It occurs in crystals and granular masses.

A typical analysis follows, the specimen coming from Valpeleina, Italy:

SiO_2	Al_2O_3	FeO	MgO	CaO	Total
54.02	.20	8.07	13.52	24.88	100.69

Schefferite is a brown or black pyroxene characterized by the fact that it contains considerable manganese. It may be regarded as hedenbergite in which a portion of the iron molecule has been replaced by the corresponding manganese molecule. A specimen from the best known locality for the species—Langban, Sweden—gave:

$SiO_2 = 52.28$, $FeO = 3.83$, $MnO = 8.32$, $MgO = 15.17$, $CaO = 19.62 = 99.22$.

It occurs in tabular crystals that are usually elongated in the direction of the zone $\infty P\bar{\infty}$ (010), $P(\bar{1}11)$, $P\bar{\infty}$ $(\bar{1}01)$ and in crystalline masses.

The mineral is yellowish brown or black, according to the percentage of iron present. Its sp. gr. is 3.46–3.55 and its fusing temperature 1200°–1250°.

A fine blue variety, known as *violan*, from St. Marcel, Italy, is characterized by the presence of about 5 per cent Na_2O, due possibly to the admixture of $NaMn(SiO_3)_2$. Its sp. gr. = 3.21.

Jeffersonite is a variety containing zinc, occurring at Franklin Furnace, N. J. It is found in large crystals with rounded edges. Its color is greenish black on fresh fractures and chocolate brown on exposed surfaces. An analysis yielded:

SiO_2	Al_2O_3	FeO	MnO	ZnO	MgO	CaO	H_2O	Total
49.91	1.93	10.53	7.00	4.39	8.18	15.48	1.20	98.62

Augite is the name given to the Ca–Mg–Fe pyroxenes containing alumina. They are isomorphous mixtures of (Ca, Mg, Fe) SiO_3 with the alumino and ferric orthosilicates of the same metals, and often with a small quantity of the acmite or jadeite molecule. The varieties of augite are numerous, their composition and properties differing with the proportions of the various molecules in the compounds. The three most prominent varieties are:

Fassaite, a pale to dark green richly magnesian variety. Sp. gr. = 2.98.

Ordinary augite, a dark green or brownish black variety, common in igneous rocks. Specific gravity 3.24. For yellow light, $\alpha = 1.712$, $\beta = 1.717$, $\gamma = 1.733$.

Diallage, a variety that is characterized by the possession of a distinct parting and a lamellar structure, usually parallel to $\infty P \bar{\infty}$ (100).

Omphacite is a bright green sodic variety. Sp. gr. = 3.33. Analyses of fassaite (I), of three varieties of augite (II, III, IV) and of omphacite (V) follow:

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	Loss	Total
I.	41.97	10.63	7.36	.55	26.60	10.29	....	2.70	100.10
II.	50.41	6.07	1.09	6.78	12.92	22.75	....	....	100.02
III.	51.01	4.84	3.51	3.16	16.58	20.80	....	....	99.90
IV.	46.95	9.75	4.47	4.09	16.04	19.02	....	....	100.32
V.	54.21	10.91	3.12	1.33	10.03	14.61	4.51	.05	100.15

I. Grass green, Fassathal, Tyrol.
II. Yellow, Monte Somma, Italy.
III. Dark green, Monte Somma, Italy.
IV. Black, Monte Somma, Italy.
V. Omphacite from the Eclogite of Ötztal, Tyrol. Also .92% K_2O and .46% TiO_2.

The augites are usually in short prismatic crystals (Figs. 201, 202). They are common constituents of igneous rocks.

All the pyroxenes of this group are subject to change under the conditions on the earth's surface. Under the influence of the weather they alter to chlorite. Under metamorphosing conditions they change into the corresponding amphiboles, more particularly into the bright green variety known as *uralite*. Alteration to serpentine is also common. Steatite, tremolite, epidote and other minerals are also frequent alteration products.

Syntheses.—Diopside and augite are common in furnace slags. They have been made by fusing their constituents in open crucibles, with or without the addition of a flux. Molten hornblende crystallizes as monoclinic pyroxene.

Occurrence.—The most common methods of occurrence of the various pyroxenes have already been mentioned. The magnesium-calcium varieties such as diopside and sahlite are found principally in metamorphic limestones. The green varieties are most common in schists and the black varieties in igneous rocks, especially the basic ones. Augite often occurs also in ore veins, especially with magnetite.

Localities.—The occurrences of the various pyroxenes are so numerous that they cannot be enumerated here. It will be sufficient to state that good crystals of diopside are found in the Ala Valley, Piedmont; at Zermatt, in Switzerland; at Pargas, in Finland; and Nordmark, in Sweden. Hedenbergite occurs at Tunaberg, Sweden, and Arendal, Norway; schefferite at Langban, Sweden, and augite at Mt. Monzoni, in the Fassathal; Traversella, Piedmont; Mt. Vesuvius, Italy; the Sandwich Islands and the Azores.

In the United States good crystals are found at Raymond and Rumford, Me. (diopside, sahlite); at Edenville and Dekalb, N. Y. (diopside); and at Franklin Furnace, N. J. (hedenbergite and jeffersonite).

Alkali Pyroxenes

The alkali pyroxenes are characterized by the presence in them of alkalis, especially sodium. They may be regarded as isomorphous mixtures of the sodium, lithium, iron and aluminium metasilicates, thus $Na_2SiO_3+Fe_2(SiO_3)_3=2NaFe(SiO_3)_2$, or $Na_2SiO_3+Al_2(SiO_3)_3=2NaAl(SiO_3)_2$. The three most common alkali pyroxenes are *acmite*, *jadeite* and *spodumene*. Spodumene is used as a source of lithium. Jadeite was formerly a favorite material from which to carve sacred emblems.

Acmite—Aegirine

Acmite has a composition corresponding to the formula $NaFe(SiO_3)_2$, and is rare. More commonly this molecule is mixed with the augite molecule in the compound known as *aegirine* or *aegirite*, or *aegirine-augite*, according to the proportion of the augite molecule present. When the mixture contains about 2.50 per cent Na_2O the corresponding mineral is usually known as aegerine-augite. When MgO and CaO are absent ($Na_2O=12$–13 per cent), it is known as acmite. Between these limits it is aegirine.

The calculated compositions of the pure acmite molecule and the

composition of specimens of acmite, aegirine and aegirine-augite as found by analyses are:

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	Total
I.	51.97	....	34.60	.....	....	....	13.43	....	100.00
II.	51.66	....	28.28	5.23	....	....	12.46	.43	100.25*
III.	49.32	4.88	16.28	5.65	4.28	9.39	8.68	.68	100.41†
IV.	50.33	.30	.....	12.37	10.98	22.01	2.14	.94	99.73‡

I. Theoretical acmite.
II. Acmite, Rundemyr, Norway.
III. Aegirine, Sarna, Dalekarlien.
IV. Aegirine-augite, Laurvik, Norway.

* Contains also .69 per cent MnO, 39 per cent H_2O and 1.11 per cent TiO_2.
† Contains also 1.25 per cent TiO_2.
‡ Contains also .66 per cent TiO_2.

Acmite crystals are usually more acicular in habit than those of the ordinary pyroxenes, and their terminations are steeper. $P(\bar{1}11)$ and $P\bar{\infty}(\bar{1}01)$ are common and $6P(\bar{6}61)$ and other steep pyramids are not uncommon (Fig. 206).

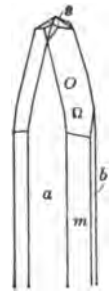


FIG. 206.—Acmite Crystal with $\infty P\bar{\infty}$, 100 (*a*); $\infty P\breve{\infty}$, 010 (*b*); ∞P, 110 (*m*); $+P$, $\bar{1}11$ (*s*); $+3P\bar{3}$, $\bar{3}11$ (*S*); $+6P$, $\bar{6}61$ (*O*) and $8P$, $\bar{8}81$ (Ω). *O* and Ω merge.

The mineral has a vitreous luster, and is transparent or translucent. Its color is reddish brown to brownish black and in some cases green. Its hardness is 6 and sp. gr. = 3.52. Its refractive indices for yellow light are: $\alpha = 1.7630$, $\beta = 1.7990$, $\gamma = 1.8126$.

Aegirine is greenish black. Its streak is yellowish gray or dark green. Pleochroism is strong in green and brown tints. Hardness is 6 and density 3.52.

Before the blowpipe acmite and aegirine fuse to a black magnetic globule. The fusing temperature of acmite is from 970° to 1020°. Both minerals are slightly attacked by acid before and after fusing.

Synthesis.—Acmite has been made by the fusion of a mixture of powdered quartz, Fe_2O_3 and Na_2CO_3 in the proportions indicated by the formula $NaFe(SiO_3)_2$.

Occurrence.—Both minerals are limited in their occurrence to soda-rich igneous rocks, in which they are primary.

Localities.—Crystals of acmite occur in a dike of pegmatite near Eker, Norway, and in a nepheline syenite at Ditro, Hungary.

Aegirine crystals are more common. They occur abundantly in the nepheline syenite dikes in the neighborhood of Langesundfjord, Norway, in some instances in crystals a foot long. They are found also in cancrinite syenites at Elfdalen and elsewhere in Sweden; in nepheline syenite on the Kola Peninsula, Russia; and in the same rock at Hot Springs, Ark.

Jadeite ($NaAl(SiO_3)_2$)

Jadeite is not known in measurable crystals, but, because sodium is almost universally present in the mineral spodumene, where it is apparently in isomorphous mixture with $LiAl(SiO_3)_2$, it is assumed that the molecule $NaAl(SiO_3)_2$ crystallizes in the same way as the spodumene and the acmite molecules. Most specimens of jadeite are isomorphous mixtures of the jadeite and diopside molecules. When in addition to these there is a notable admixture of the acmite molecule, $NaFe(SiO_3)_2$, the mineral is known as *chloromelanite*.

The mineral is of great ethnological interest because so many ornaments were made of a rock composed mainly of jadeite by the ancient inhabitants of China, Mexico, South America and elsewhere. "Jade" ornaments, however, are not all made of jadeite, but in all instances their material resembles this mineral in color, structure and density. Many of them are made of fibrous amphiboles, some of which correspond to jadeite in composition.

The theoretical composition of the mineral is given in line I, and the analyses of specimens from Mexico and China in lines II and III:

	SiO_2	Al_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O	Total
I.	59.39	25.56	....	....	....	15.35	...	...	100.00
II.	58.18	23.53	1.67	1.72	2.35	11.81	.77	.53	100.56
III.	58.68	21.56	.94	2.49	3.37	13.09	.49	...	100.62

I. Theoretical.
II. Oaxaca, Mexico.
III. Ornament, China.

Jadeite occurs in fibrous, flaky and dense, finely granular masses with a glassy luster, inclining to pearly on cleavage surfaces. Its color is in some cases white or yellowish white, but more frequently bright green or bluish green. Its streak is white. Its cleavages make angles of 87°. Its fracture is tough and splintery. Its hardness is 6.7 and its density 3.3–3.35. Its intermediate index of refraction, $\beta = 1.654$.

Before the blowpipe jadeite fuses easily to a transparent, blebby glass. It is unattacked by acids. After fusion, however, it is easily decomposed

by HCl and sometimes by Na_2CO_3. At high temperatures (225°-235°) it is also decomposed by water.

Jadeite alters by metamorphic processes to a white hornblende (tremolite).

Localities.—Ornaments and instruments made of jadeite, and water-worn fragments of the mineral are known from many localities in China, Tibet, Burma, Switzerland, France, Egypt, Italy, Mexico and Central America. The original sources of the material of the ornaments are not known. The mineral, however, occurs with albite and nepheline in a dike at Tawman, Burma, and probably as a constituent in some metamorphic schists.

Spodumene ($LiAl(SiO_3)_2$)

Spodumene is essentially the lithium molecule corresponding to the sodium molecule jadeite. Nearly always, however, the mineral contains some of the sodium molecule, and a small quantity of helium. Three typical analyses are quoted below:

	Theoretical	Colorless, Branchville, Conn.	Yellowish green, Minas Geraes, Brazil	Kunzite, S. Diego Co., Cal.
SiO_2...	64.49	64.25	64.32	64.42
Al_2O_3..	27.44	27.20	27.79	27.32
Fe_2O_3...	.....	.20	.....	.....
Mn_2O_3.	.....	.....	.....	.15
FeO...	.....	.....	.67	.....
CaO...	.....	.....	.17	.....
Li_2O...	8.07	7.62	7.45	7.20
Na_2O..	.....	.39	.55	.39
K_2O...	.....	.....	.....	.03
H_2O...	.....	.24	.12	
Total.	100.00	99.90	101.07	99.51

Crystals are usually columnar parallel to ∞P (110) or tabular parallel to ∞P$\bar{\infty}$ (100) (Fig. 207). They are more complex than those of the members of the diopside-augite group and their habit is different. The most frequent forms are ∞P$\bar{\infty}$ (100), ∞P$\breve{\infty}$ (010), ∞P(110), ∞P$\breve{2}$(120), ∞P$\breve{3}$(130), 2P$\breve{\infty}$ (021), 2P($\bar{2}$21) and P($\bar{1}$11). Some of them are of enormous size. In the Etta Mine, Black Hills, South Dakota, are many 30 ft. long and 3-4 ft. in diameter. One measured 47 ft. in length. Most crystals are striated vertically. Twins are

fairly common, with $\infty P(110)$, the twinning plane. Although crystals are not uncommon the mineral more frequently occurs as platy or scaly aggregates. The angle $110 \wedge 1\bar{1}0 = 93°$.

Spodumene has a glassy luster, which is pearly on cleavage surfaces. Its color is white, gray, greenish or yellowish green, or amethystine. It is transparent or translucent, and its streak is white. Its fracture is uneven or conchoidal, its hardness between 6 and 7 and its density 3.2. Dark green crystals exhibit marked pleochroism. Refractive indices for yellow light in specimens from North Carolina are: $\alpha = 1.651$, $\beta = 1.669$, $\gamma = 1.677$.

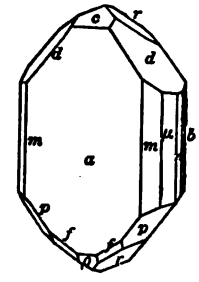


FIG. 207.—Spodumene Crystal with $\infty P\bar{\infty}$, 100 (*a*); $\infty P\bar{\infty}$, 010 (*b*); ∞P, 110 (*m*); $\infty P\bar{2}$, 120 (*μ*); $\infty P\bar{3}$, 130 (*n*); $2P\bar{\infty}$, 021 (*d*); $+2P$, $\bar{2}21$ (*r*); $+P$, $\bar{1}11$ (*p*); $2P\bar{2}$, $\bar{2}11$ (*f*) and $P\bar{\infty}$, $\bar{1}01$ (*ρ*).

Two varieties have been named and used as gems. These are:

Hiddenite, a glassy emerald-green variety, from Alexander Co., N. C.

Kunzite, a pink or lilac variety, from San Diego Co., California. Under the influence of radium rays it becomes green. When heated to 240° it becomes a darker rose color, but at 400° it loses all color.

Before the blowpipe the mineral swells up and fuses to a colorless glass, at the same time imparting a crimson color to the flame. It is unattacked by acids. It melts at about 1325°. Its powder reacts alkaline.

It alters readily to albite, muscovite, *eucryptite* ($LiAlSiO_4$), or mixtures of these. One of the commonest mixtures is known as *cymatclite* or *cumatolite*. The mixture of albite and eucryptite has been called β spodumene.

Spodumene crystals have not been made artificially.

Occurrence and Origin.—The mineral occurs in granites, pegmatites and crystalline schists, where it was formed by pneumatolytic processes. It is often associated with cassiterite.

Localities.—Spodumene crystals occur at Huntington, Mass., in a quartz vein in mica schist; at Branchville, Conn., in pegmatite; at Stony Point in Alexander Co., N. C., in cavities in a gneiss; at the Etta Mine and at other places in the Black Hills, N. D., in a pegmatite; at the lepidolite localities in California and in Minas Geraes, in Brazil.

Uses.—The ordinary varieties of the mineral are used as a source of lithium in the manufacture of lithium salts, and the transparent varieties

as gems. The total production of kunzite in this country during 1912 was valued at $18,000, all from California. One specimen found in this year weighed $47\frac{1}{2}$ oz. Another was a crystal measuring $9 \times 5 \times \frac{3}{4}$ inches. The other forms of the mineral were not mined. In recent years a few tons have been furnished by the mines in the Black Hills.

TRICLINIC PYROXENES

The triclinic pyroxenes include the four minerals *rhodonite*, *bustamite*, *fowlerite* and *babingtonite*. They are completely isomorphous. The first is the manganese metasilicate, $MnSiO_3$, and the others are isomorphous mixtures of this molecule with the corresponding silicate of calcium (bustamite), or of these two with the corresponding iron (babingtonite), or with the iron and zinc compounds (fowlerite).

Rhodonite—Fowlerite ($R''MnSiO_3$. R = Ca,Fe,Zn)

Rhodonite is the pure manganese silicate with the percentage composition shown in I. In II is the result of an analysis of crystals from Pajsberg, Sweden. An analysis of bustamite from Campiglia, Italy, is quoted in III and one of fowlerite from Franklin Furnace, N. J., in IV.

	SiO_2	Al_2O_3	MnO	FeO	ZnO	MgO	CaO	H_2O	Total
I.	45.85	...	54.15	....	....	....	.....	....	100.00
II.	45.86	...	45.92	.36	....	1.65	6.40	....	100.09
III.	49.23	.37	26.99	1.72	....	1.81	18.72	1.54	100.38
IV.	46.06	...	34.28	3.63	7.33	1.30	7.04	....	99.64

All are triclinic (pinacoidal class), with the axial constants of 1.0729 : 1 : .6213, $\alpha = 103° 19'$, $\beta = 108° 44'$, $\gamma = 81° 39'$ for rhodonite, and 1.0807 : 1 : .6237 and $\alpha = 102° 27'$, $\beta = 108° 34'$, $\gamma = 82° 53'$ for babingtonite. Their crystals possess many habits, of which the cubical, tabular, and columnar are the most common. They are usually rough with rounded edges. The most frequently occurring forms are oP(001), $\infty P\bar{\infty}$ (100), $\infty P\bar{\infty}$ (010), $\infty P'$(110), $\infty'P(1\bar{1}0)$, $P_{/}(11\bar{1})$ and $2_{/}P(\bar{2}21)$ (Fig. 208). The angle $100 \wedge 001 = 72° 37'$. Their cleavage

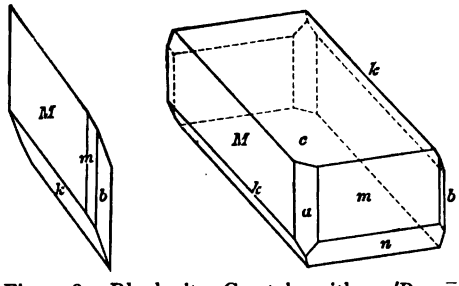


Fig. 208.—Rhodonite Crystals with $\infty'P$, $1\bar{1}0$ (*M*); $\infty P'$, 110 (*m*); oP, 001 (*c*); $\infty P\bar{\infty}$, 100 (*a*); $\infty P\bar{\infty}$, 010 (*b*); $2_{/}P$, $\bar{2}21$ (*k*) and $2P_{/}$, $22\bar{1}$ (*n*).

is perfect parallel to $\infty P'(110)$ and $\infty 'P(1\bar{1}0)$. Although crystals are fairly common in some places, the minerals are more usually in dense, structureless or finely granular masses.

All the triclinic pyroxenes have a glassy luster which is somewhat pearly on cleavage surfaces. They are transparent or translucent and all except babingtonite have a rose-red color when pure. When mixed with other substances their color may be yellowish, greenish, brownish or black. They are pleochroic in rose and yellowish tints. Their streak is always reddish white. Babingtonite is greenish black and is pleochroic in green and brown tints. All have an uneven fracture. Dense varieties are tough and their crystals are brittle. Their hardness = 5–6, and density 3.4–3.7. The intermediate refractive index of rhodonite is 1.73 for yellow light.

Before the blowpipe all become black, swell and fuse to a brown glass. The fusing temperature of rhodonite is about 1200° and of bustamite about 1300°. They are attacked by acids with loss of color.

When exposed to the weather the members of the group containing manganese alter to a mixture of which the principal constituents are a manganese oxide, Mn_2O_3, silica and water, or to mixtures of carbonates of manganese, or a mixture of the carbonates of manganese, iron and calcium.

Syntheses.—Crystals of rhodonite have been prepared by fusing a mixture of SiO_2 and MnO_2 and by passing a current of steam and CO_2 over a red-hot mixture of $MnCl_2$ and SiO_2. Rhodonite and babingtonite crystals are also formed in the slags of manganese iron furnaces, and the latter has been found in cavities in roasted iron ores.

Occurrence.—The members of the group containing manganese occur in veins of magnetite, copper and other metals, and in contact zones between limestones, shales and igneous rocks, associated with other manganese minerals. Under these conditions they may have been produced by the help of magmatic emanations. Rhodonite occurs also with rhodochrosite in deposits of manganese ores and in other associations, where it may be of secondary origin. Babingtonite occurs principally as a rare component of siliceous rocks.

Localities.—Crystals of rhodonite and bustamite occur in iron ore deposits in the gneiss of Langban, Sweden. Fine crystals of rhodonite are found in the iron ore at Pajsberg, Sweden, and crystals of fowlerite in metamorphosed limestone associated with the zinc ores at Stirling Hill and Franklin Furnace, N. J. Massive rhodonite is abundant at Jekaterinburg, Ural, Russia; at Kapnik, Hungary; at Blue Hill Bay, Maine; and in Jackson Co., N. C., associated with wad. Massive bus-

tamite occurs at Rézbánya, Hungary, in veins in limestone, and at Mts. Civillina and Campiglia, Italy, in fibrous masses. Babingtonite occurs in a mica schist at Athol, Mass., and in druses in granite at Baveno, Italy, and in the ore veins at Arendal, Norway.

The principal occurrences of gem rhodonite in this country are in Siskiyou Co., Cal., and near Butte, Mont. In the former locality the mineral occurs nine miles north of Happy Camp in a fine-grained quartz schist. It consists of a mixture of quartz grains cemented by rhodonite and traversed by veins of pyrolusite. The Montana material is in radiating groups with quartz, pyrite and brown manganese oxide. At the Alice Mine it is associated with rhodochrosite.

Uses and Production.—Transparent rhodonite is used as a gem-stone to a slight extent. The total yield of the material in the United States during 1912 was valued at $550.

THE AMPHIBOLES

($R''SiO_3$, $R'Al(SiO_3)_2$ and $R''(R'''O)_2SiO_4$)

The amphiboles are common alteration products of pyroxenes and some other silicates. They are also abundant as components of certain schistose rocks, as for instance, the hornblende schists, and they occur also as original constituents of igneous rocks. The crystals of all the amphiboles are similar in habit to those of the pyroxenes (Fig. 209), but since the ratio between the *a* and *b* axes is about .5 to 1, the angles between their cleavage planes, which, like those of the pyroxenes, are parallel to ∞P(110), are from 54° to 56° and 124° to 126° (see Fig. 198B). The plane of symmetry bisects the obtuse angle.

The members of the group are about as numerous as those of the pyroxenes, but the common types are much fewer. Moreover, there is no subgroup corresponding to the wollastonite subgroup of the pyroxenes. The best known members of the series, with their axial ratios are:

Orthorhombic (possibly twinned monoclinic).

Anthophyllite	$(Mg \cdot Fe)SiO_3$	$a : b : c = .521 : 1 : .2\pm$	
Gedrite	$(Mg \cdot Fe)(AlO)_2SiO_4$	$= .523 : 1 : .217$	

Monoclinic (monoclinic prismatic class).

Tremolite	$Mg_3Ca(SiO_3)_4$	$a : b : c = .5415 : 1 : .2886$	$\beta = 74° 49'$
Actinolite	$(Mg \cdot Fe)_3Ca(SiO_3)_4$		
Cummingtonite	$(Fe \cdot Mg)SiO_3$		
Grünerite	$FeSiO_3$		
Hornblende	$(Mg \cdot Fe)_3Ca(SiO_3)_4$ $(Mg \cdot Fe)((Al \cdot Fe)O)_2SiO_4$ $NaAl(SiO_3)_2$	$= .5318 : 1 : .2937$	$\beta = 75° 02'$

Glaucophane	$\left\{\begin{matrix} NaAl(SiO_3)_2 \\ (Fe\cdot Mg)SiO_3 \end{matrix}\right\}$	$=.53 : 1 : .29$	$\beta=77°$
Arfvedsonite	$\left\{\begin{matrix} (Na_2\cdot Ca\cdot Fe)SiO_3 \\ (Ca\cdot Mg)((Al\cdot Fe)O)_2SiO \end{matrix}\right\}$	$=.5496 : 1 : .2975$	$\beta=75°45'$
Riebeckite	$NaFe(SiO_3)_2$	$=.5475 : 1 : .2925$	$\beta=76°10'$
Crocidolite	$\left\{\begin{matrix} NaFe(SiO_3)_2 \\ FeSiO_3 \end{matrix}\right\}$		

Triclinic (triclinic pinacoidal class).

Aenigmatite	$Na_4Fe_9(Al\cdot Fe)_2(Si\cdot Ti)_{12}O_{38}$	$=.6778 : 1 : .3506$	$\beta=72°49'$

ORTHORHOMBIC AMPHIBOLES

Anthophyllite—Gedrite

The orthorhombic amphiboles are comparatively rare. They are isomorphous mixtures of $MgSiO_3$, $FeSiO_3$ and the alumino-orthosilicates $(Mg\cdot Fe)(AlO)_2SiO_4$. The pure $MgSiO_3$ has not been found in nature, but it has been produced in the laboratory. The mixture of the magnesium and iron silicates $(Mg\cdot Fe)SiO_3$, is known as ***anthophyllite.*** In nature it always contains a little of the molecule $(Mg\cdot Fe)(AlO)_2SiO_4$. *Gedrite*, which is much less common than anthophyllite, contains more Al_2O_3 than does this mineral, which may be regarded as due to a larger admixture of the molecule $(Mg\cdot Fe)(AlO)_2SiO_4$. The name is thus applied to aluminous anthophyllites.

The difference in composition of the two minerals is shown by the following analyses of (I) anthophyllite and (II) gedrite.

	SiO_2	Fe_2O_3	Al_2O_3	MnO	FeO	MgO	CaO	Na_2O	H_2O	Total
I.	57.98	...	.63	.31	10.39	28.69	.20	....	1.79	99.99
II.	46.18	.44	21.78	...	2.77	25.05	...	2.30	1.37	99.89

I. Brown crystals; Franklin, Macon Co., N. C.
II. Colorless prisms; Fiskernas, Greenland.

The orthorhombic amphiboles usually occur in platy or fibrous aggregates that rarely show traces of end faces, and, consequently the ratio between *c* and *b* is not accurately known. The planes in the prismatic zone are, however,[1] sometimes so well developed that they can be recognized as $\infty P\bar{\infty}$ (100), $\infty P\breve{\infty}$ (010), and ∞P(110). Cleavage is perfect parallel to ∞P(110) and distinct parallel to $\infty P\breve{\infty}$ (010). The cleavages intersect at angles 54° 20′–55° 18′.

The minerals have a glassy luster which is slightly pearly on cleavage surfaces. They are green or brown in color and have a colorless, yellow white or gray streak and are translucent and pleochroic in colorless,

greenish and brownish tints. Their fracture is somewhat conchoidal. Hardness is 5.5. and density 3.2. The refractive indices for yellow light in anthophyllite are: $\alpha = 1.633$, $\beta = 1.642$, $\gamma = 1.657$; and in gedrite, 1.623, 1.636, and 1.644.

Synthesis.—Pure magnesium metasilicate has been made in orthorhombic crystals mixed with monoclinic crystals, by rapid cooling of a magma made by heating Mg salts and silica with water at 375°–475°

Occurrence.—The minerals are found in crystalline schists—more particularly in hornblende gneisses and hornblende schists, where they are distinctly metamorphic minerals, having been derived in some cases, at least, by the alteration of the orthorhombic pyroxenes. They alter to talc.

Localities.—Anthophyllite occurs in dark brown platy aggregates at Kongsberg and Modum in Norway, associated with hornblende in mica schists; on the Shetland Islands, Scotland, associated with serpentine; and at the Jenks Corundum Mine in Macon Co., N. C.

Gedrite occurs in yellowish gray fibrous aggregates at Bamle, Norway, in dark brown aggregates associated with magnetite and brown mica, at Gedres, Hautes-Pyrénées, France; and in a mica schist at Fiskernas, Greenland, associated with a large number of metamorphic minerals.

MONOCLINIC AMPHIBOLES

The monoclinic amphiboles, like the corresponding pyroxenes, comprise isomorphous mixtures of the metasilicates of Na, Mg, Ca and Fe

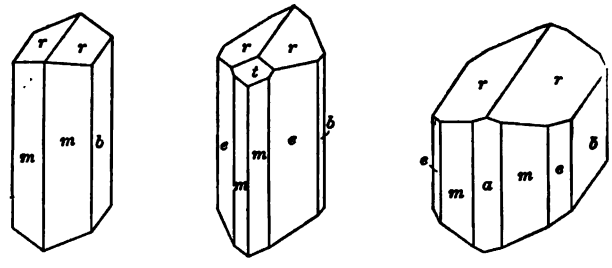


FIG. 209.—Ampibole Crystals with ∞P, 110 (*m*); ∞P$\bar{\infty}$, 010 (*b*); ∞P$\bar{3}$, 130 (*e*); P$\bar{\infty}$, 011 (*r*) and −P$\bar{\infty}$, 101 (*t*).

and the basic orthosilicates of Al and Fe. Recent work seems to indicate that in tremolite there is present also a little H_2O. In the amphiboles the alumino-silicate is more common than in the pyroxenes and consequently aluminous amphiboles are more common than aluminous pyroxenes.

All the monoclinic amphiboles crystallize with the same habit in crystals that are columnar like those of the corresponding pyroxenes, but on which the terminations are different (Fig. 209). Moreover, all have a distinct cleavage parallel to $\infty P(110)$ with cleavage angles of about 56°–124°.

The amphiboles are distinguished from other minerals by their crystallization and their cleavage.

For convenience, the monoclinic amphiboles may be subdivided into (1) the magnesium-calcium-iron amphiboles including *tremolite*, *actinolite*, *cummingtonite*, *grünerite* and *hornblende*, and (2) the alkali amphiboles, including *arfvedsonite*, *glaucophane* and *riebeckite*.

Before the blowpipe all the members of the group fuse to a glass which is colorless, green or black, according to the quantity of iron present. The varieties rich in iron are attacked by acids.

Magnesium-Calcium-Iron Amphiboles

Tremolite-Hornblende

This group includes the monoclinic amphiboles that are mainly metasilicates of magnesium and iron and the mineral hornblende, which is a mixture of these molecules and the orthosilicate $(Mg \cdot Fe)((Al \cdot Fe)O)_2SiO_4$. The calcium metasilicate is present in some members as an isomorphous mixture, but it does not occur alone as an independent member corresponding to wollastonite among the pyroxenes. Hornblende is the only member of the series that is essentially aluminous.

The crystals of the monoclinic amphiboles are short columnar or long and acicular. Their axial ratios are nearly alike and their cleavage angles differ only by a few minutes. The simpler crystals are bounded by $\infty P\bar{\infty}(100)$, $\infty P\breve{\infty}(010)$, $\infty P(110)$, $oP(001)$, $3P\breve{\infty}(031)$, $+P\bar{\infty}(\bar{1}01)$, $-P\bar{\infty}(101)$, $2P\bar{2}(\bar{1}21)$, $2P\bar{2}(211)$ and $P\breve{\infty}(011)$ (Fig. 209). Contact twins are common, with $\infty P\bar{\infty}(100)$ the twinning plane as in the pyroxenes. Polysynthetic twins are rare.

All the amphiboles of this group have a glassy luster and are transparent or translucent. All the members but hornblende are white or some shade of green, though colorless and brown varieties are not uncommon and yellow and red varieties are known. Hornblende is frequently so dark as to be almost black. Their streak is light, hardness is 5–6 and density 2.9–3.4, depending upon composition.

The cleavage is perfect in all the amphiboles and there is present often also a parting parallel to $\infty P\bar{\infty}(100)$ and $P\bar{\infty}(\bar{1}01)$, the latter due to gliding. Pleochroism is strong in all the colored varieties in green

and yellowish green tones in the green varieties, and brown and yellowish brown tints in the brown varieties.

Tremolite is the calcium magnesium silicate. When there is mixed with this the corresponding iron molecule the mixture is known as *actinolite* if the proportion of the iron molecules present is not great. The theoretical compositions of the two molecules $Mg_3Ca(SiO_3)_4$ and $Fe_3Ca(SiO_3)_4$ are given in lines I and II, and analyses of several tremolites and actinolites in lines III, IV, V and VI. The almost universal presence of small quantities of water in tremolite, and the lack of enough Mg, Ca, Fe and other metallic bases to satisfy all the SiO_2 revealed by the analyses has suggested to some mineralogists that the water is an essential part of the compound, and that its composition is best represented by $Mg_5Ca_2H_2(SiO_3)_8$.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	H_2O	Total
I.	57.72	...	....	.....	28.83	13.45	....	....	100.00
II.	46.90	...	....	42.17	.....	10.93	....	....	100.00
III.	58.27	.33	tr.	.....	25.93	11.90	1.25	1.22	99.40*
IV.	57.40	.38	....	1.36	25.69	13.89	....	.40	99.12
V.	58.80	...	....	3.05	22.23	16.47	....	....	100.55
VI.	55.50	...	....	6.25	22.56	13.46	....	1.29	99.06

I. Theoretical for $Mg_3Ca(SiO_3)_4$.
II. Theoretical for $Fe_3Ca(SiO_3)_4$.
III. Tremolite, Easton, Pa.
IV. Tremolite, Gouverneur, N. Y.
V. Asbestus, Bolton, Mass.
VI. Actinolite, Greiner, Zillerthal, Tyrol.

* Also .08 MnO and .42 K_2O.

Tremolite is white or nearly white, and actinolite is green. The former occurs in columnar crystals, in plates and occasionally in fibers, while actinolite is nearly always in long, slender acicular crystals without terminations. The refractive indices for yellow light in tremolite are: $\alpha=1.6065$, $\beta=1.6233$, $\gamma=1.6340$. In actinolite, $\alpha=1.6116$, $\beta=1.6270$, $\gamma=1.6387$.

Both minerals melt in the blowpipe flame, the fusing temperature for tremolite being about 1290° and for actinolite about 1150°.

Asbestus is a fibrous variety of tremolite, actinolite or anthophyllite. It occurs principally in rocks that have been crushed and sheared under great pressure. The actinolite asbestus is used for the same purpose as the chrysotile variety (see p. 398), but it is regarded as less valuable.

Its principal source in this country is Salls Mountain, Georgia, but promising deposits have recently been reported near Kamiah, Idaho. At the Georgian locality the asbestus forms distinct lenses in gneiss. It is possibly an altered basic intrusive rock.

Smaragdite is a grass-green actinolite, which is often an alteration product of pyroxenes and olivine. The name is also applied to a bright green hornblende containing a little chromium.

Nephrite is a finely fibrous actinolite or tremolite and usually some chlorite, forming dense rock masses that are white or of a light green color. It was formerly much used, like jade, in the manufacture of images, charms and implements.

Cummingtonite and **grünerite** are amphiboles containing notable quantities of the molecule $FeSiO_3$. In grünerite, the quantity of Mg present is very small but in cummingtonite it is fairly large. Because of its similarity to anthophyllite, this mineral is frequently referred to as amphibole-anthophyllite. It is intermediate in composition between grünerite and actinolite. Analyses of specimens from several well known localities are quoted below.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	H_2O	Total
I.	57.26	.75	1.73	15.64	21.70	tr.	2.80	....	99.88
II.	47.17	1.00	1.12	43.40	2.61	1.90	.47	2.22	100.08

I. Cummingtonite, near Baltimore, Md.

II. Grünerite, Collobrières, France. Contains also, F=.07, K_2O=.07 and MnO=.08.

These two minerals are comparatively rare and have not always been recognized as worthy of different names. In general appearance they are much like actinolite, though perhaps more brown or gray in color, and they occur in nearly the same association. The specific gravity of cummingtonite varies between 3.1 and 3.3 and that of grünerite is about 3.52. The intermediate refractive index for yellow light is 1.62–1.65 in cummingtonite and 1.697 in grünerite.

Hornblende is the name given to the monoclinic aluminous amphiboles that contain only a small quantity of alkalies. In other words, most of the hornblendes are isomorphous mixtures of the actinolite molecule and the molecules $(Mg \cdot Fe)((Al \cdot Fe)O)_2SiO_4$ and $(Na \cdot K)Al(SiO_3)_2$. The varieties containing Na_2O (known as *katoforite*) correspond to aegirine among the pyroxenes.

The varieties of hornblende that are distinguished by distinctive names are:

Pargasite, the green, bluish green or greenish black variety, and

Edenite, the white, gray or light green variety, both of which contain very little iron in either the ferrous or ferric condition,

Smaragdite, a bright green chromiferous variety of pargasite,

Common hornblende, the greenish black variety,

Basaltic hornblende, which contains a large proportion of ferric iron and is black in color.

Their refractive indices for yellow light are as follows:

	α	β	γ
Pargasite, Pargas, Finland	1.613	1.620	1.632
Common Hornblende, Kragerö, Norway	1.629	1.642	1.653
Basaltic hornblende, Bohemia	1.680	1.725	1.752

The fusing temperature of pargasite is about 1150° and of hornblende about 1200°.

Analyses of typical specimens of these varieties follow:

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	Ign	Total
I.	51.69	4.17	2.34	9.83	17.17	12.17	.82	.79	1.13	100.25
II.	42.97	16.42	.....	1.32	20.14	14.99	1.53	2.85	.87	102.75
III.	49.33	12.72	1.72	4.63	17.44	9.91	2.25	.63	.29	99.13
IV.	39.17	14.37	12.42	5.86	10.52	11.18	2.48	2.01	.39	99.91

I. Common Hornblende, Vosges. Also .14 per cent TiO_2.
II. Pargasite, Pargas, Finland. Also 1.66 per cent F.
III. Edenite, Saualpen, Carinthia. Also 1.21 per cent F.
IV. Basaltic, Jan Mayen, Greenland. Also 1.51 per cent MnO.

Among the commonest forms of alteration in the amphiboles are the following: Tremolite into talc (p. 401) and serpentine, and hornblende into serpentine, chlorite (p. 428), epidote and biotite, often with the addition of magnetite and other iron compounds in cases where iron was present in the original mineral. Most of these changes are brought about by regional metamorphism. The production of biotite is also brought about by the action of magmas. The common weathering products of hornblende are chlorite, epidote, calcite, quartz, magnetite and siderite. Under the conditions of high temperature and high pressure, hornblende sometimes passes over into augite and magnetite.

Syntheses.—Amphibole crystals have not been found in slags nor have they been made by dry fusion. Crystals of hornblende, however,

have been obtained by heating to 555° for three months, a mixture of its components in a glass tube with water.

Occurrence.—Tremolite occurs in crystalline limestones and dolomites that have been subjected to regional metamorphism and in crystalline schists. Actinolite, cummingtonite and grünerite are found in crystalline schists, in some cases in such large quantity as to constitute essential parts of the rocks. Actinolite schists are such rocks containing in addition to the actinolite some quartz, epidote and chlorite. Grünerite schists consist essentially of grünerite, actinolite, magnetite and quartz.

Common hornblende occurs in igneous and metamorphic rocks, such as gneisses and schists. In some schists, as the amphibolites, it is the principal constituent and in others, the hornblende schists, it is the principal component other than quartz. The mineral is also a common metamorphic alteration product of pyroxenes which it frequently pseudomorphs. When the pseudomorphing hornblende is blue-green and fibrous it is known as *uralite.* The chemical changes attending this alteration are illustrated by the analyses of a pyroxene (I) from the Grua Tunnel in Norway and of the uralite (II) produced from it.

	SiO_2	Fe_2O_3	Al_2O_3	FeO	MnO	CaO	MgO	Na_2O	Loss	Total
I.	50.53	1.91	.27	7.81	1.99	24.51	10.92	.48	.26	100.37*
II.	42.02	2.30	3.25	9.30	.94	20.90	9.63	.45	1.07	100.04*

* Also .19 per cent K_2O in I and .26 per cent in II.

Basaltic hornblende is found only in igneous rocks, and especially those rich in iron.

Edenite occurs in crystalline limestones that have been metamorphosed by contact action.

Pargasite is in gneisses and crystalline limestones.

Localities.—Tremolite crystals occur at Campolonga, Switzerland; at Rézbánya, Hungary; at New Canaan, Conn.; and at Diana, Lewis Co., N. Y. It occurs also in flat plates at Lee, Mass.; near Byram, N. J.; at Easton, Penn.; at Edenville, N. Y.; and at Litchfield, Me., and other places in the limestones in Quebec, Canada.

Actinolite occurs with chlorite at the Zillerthal, Tyrol; in talc and chlorite schists near Jekaterinburg, Ural, Russia; at Arendal, Norway; at Willis Mt., Buckingham Co., Va.; at the Bare Hills, Md.; at Mineral Hill, in Delaware Co., and at Unionville, Penn., in the soapstone quarries at Windham and New Fane, Vt.; at Bolton, Brome Co., Quebec, and at many other points.

Asbestus is abundant at Sterzig, in Tyrol; on the Island of Corsica; near Greenwood Furnace, N. Y.; in the Bare Hills, near Baltimore, Md.; at Pylesville, Harford Co., in the same State; at Barnet's Mills, Fauquier Co., Va., and at the localities at which it has been mentioned as being mined.

The principal occurrences of cummingtonite are Kongsberg, Norway, Cummington, Mass.; and a layer in gneisses and schists at Mt. Washington, Md.

Grünerite occurs in a rock composed of this mineral, garnet and hematite near Collobrières, Var., France. It has also been described as the principal constituent of certain schists in the Lake Superior iron region, but since the amphibole in these rocks contains a notable quantity of MgO it should better be classed with cummingtonite.

The localities at which crystals of the hornblendes have been found are very numerous. Excellent crystals occur in the volcanic bombs in the Lake Laach district, Prussia; in cavities in inclusions within the lavas of Aranyer Mt., Siebenburgen, Hungary; in the dikes of porphyry, near Roda, Tyrol; on the walls of cavities in inclusions in the lavas at Vesuvius, Italy; and at various points in Sweden, etc.. In North America fine crystals are found at Thomaston, Me.; at Russell and Pierrepont, N. Y.; at Franconia, N. H.; and in the glacial debris at Jan Mayen, Greenland. Pargasite occurs at Pargas, Finland, and Phippsburg, Me.

Alkali Amphiboles

The alkaline amphiboles include *riebeckite*, *crocidolite*, *glaucophane* and *arfvedsonite*. The first two are nonaluminous iron-soda amphiboles and the last two are aluminous compounds. Glaucophane contains the molecule $NaAl(SiO_3)_2$ which is found also in hornblende, and, therefore, it may be regarded as a connecting link between the common and the alkaline amphiboles. Glaucophane differs from hornblende, however, in containing very little CaO. The intermediate link *katoforite* bridges the gap between the two.

$$\textbf{Glaucophane} \left\{ \begin{array}{l} \mathbf{NaAl(SiO_3)_2} \\ \mathbf{(Fe \cdot Mg)SiO_3} \end{array} \right\}$$

Glaucophane is, theoretically, a mixture of the two molecules $NaAl(SiO_3)_2$ and $(Fe \cdot Mg)SiO_3$. It is essentially a mixture of the cummingtonite molecule with one corresponding to the jadeite molecule

among the pyroxenes. An analysis of a specimen of katoforite (compare p. 387) from the sanidinite bombs in the lava at Sao Miguel, Azores, is quoted in line I for comparison with the two glaucophane analyses in lines II and III.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	Total
I.	45.53	4.10	9.35	23.72	2.46	4.89	6.07	.88	99.96
II.	56.65	12.31	3.01	4.58	12.29	2.20	7.93	1.05	100.02
III.	56.71	15.14	9.78	4.31	4.33	4.80	4.83	.25	100.15

I. Katoforite, Sao Miguel, Azores. Also 2.96 per cent TiO_2.
II. Glaucophane, Ile de Groix.
III. Glaucophane, Shikoku, Japan.

Glaucophane is rarely found in crystals with end faces. Even when these exist they are rough and yield poor measurements.

The mineral occurs in columnar crystals, in needles and in foliated or granular aggregates in rocks. Their prismatic planes are $\infty P \bar{\infty}$ (100), $\infty P \bar{\infty}$ (010) and ∞P(110). P($\bar{1}$11) and oP(001) are the only terminations that have been identified. The cleavage angle is about 55° 20′.

Glaucophane is blue or bluish black, translucent and strongly pleochroic in yellowish, violet and blue tints. Its streak is grayish blue, its fracture uneven, its hardness about 6 and its density 3. Its refractive indices for yellow light are: $\alpha = 1.6212$, $\beta = 1.6381$, $\gamma = 1.6300$.

Before the blowpipe the mineral turns brown and then melts to an olive-green glass. It is difficultly attacked by acids.

Glaucophane is distinguished from the other amphiboloids by its color, and from other blue silicates by its crystallization, hardness and manner of occurrence.

It is usually unaltered but it has been described in one instance as being partially changed to chlorite.

Synthesis.—It has not been produced artificially.

Occurrence.—The mineral is found only in metamorphosed limestones, in mica schists and in the garnet rock known as eclogite. It is characteristically a metamorphic mineral.

Localities.—Glaucophane occurs in long crystals in various schists in Syra, Cyclades, Greece; in hornblende schists in the Ile de Groix, Brittany, France; in a glaucophane schist on the Island of Shikoku, Japan; and abundantly in various schists in the Coast Ranges of California.

Arfvedsonite, Riebeckite and Crocidolite

These amphiboles are comparatively rare. They occur principally in coarse-grained alkaline igneous rocks, usually as prismatic grains without terminations, embedded in the rock mass. Arfvedsonite, however, in some cases, occurs in groups of crystals on some of which terminations can be identified.

Riebeckite, $NaFe(S \cdot O_3)_2$, has a composition very near that of acmite, and crocidolite contains, in addition, the molecule $FeSiO_3$. Arfvedsonite is much more complex than either of these and has no equivalent among the pyroxenes. Analyses of typical specimens of the two minerals are quoted below. In line IV is an analysis of crocidolite.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	K_2O	Na_2O	H_2O	Total
I.	47.08	1.44	1.70	35.65	...	2.32	2.88	7.14	2.08	100.29
II.	49.65	1.34	17.66	19.55	...	3.16	....	7.61	1.67	100.64
III.	50.01	....	28.30	9.87	.34	1.32	.72	8.79	....	99.98
IV.	51.03	....	17.88	21.19	.09	....	....	6.41	3.64	100.24

I. Black arfvedsonite, Kangerdluarsuk, Greenland.
II. Riebeckite from granite, Quincy, Mass.
III. Riebeckite from Socotra, Indian Ocean.
IV. Dark blue radial aggregates of crocidolite, Cumberland, R. I.

Arfvedsonite is usually in long prisms flattened parallel to $\infty P \bar{\infty}$ (010), but otherwise very much like hornblende. It is black or dark green and translucent, and has a dark bluish gray streak. Its hardness is 6 and density 3.4–3.5. It is strongly pleochroic. Thin splinters parallel to $\infty P \bar{\infty}$ (010), are olive green and those parallel to $\infty P \bar{\infty}$ are deep greenish blue. Its refractive indices for yellow light are: $\alpha = 1.687$, $\beta = 1.707$, $\gamma = 1.708$.

Before the blowpipe the mineral fuses easily to a black magnetic globule and colors the flame yellow. It is not acted upon by acids.

Riebeckite is found only in embedded prisms, showing no terminations. It is black, vitreous and very pleochroic in green and dark blue tints. Its density is about 3.3, and its hardness 5.5–6. Its refractive index for yellow light is about 1.687. Before the blowpipe it fuses easily, imparting an intense yellow color to the flame.

Crocidolite is an asbestus-like, lavender-blue or dark green riebeckite, that contains a larger amount of iron, due to the presence of the molecule $FeSiO_3$. It occurs also in earthy masses. Its streak is lavender-blue or leek-green and its hardness is 4. In all cases it appears to be a secondary mineral. The green fibrous variety is known as " cat's-eye."

Both riebeckite and arfvedsonite weather to aggregates of iron oxides, quartz and carbonates. The decomposed, brown crocidolite is the well-known ornamental stone " tiger's-eye."

Occurrence and Localities.—Arfvedsonite is found principally in igneous rocks rich in soda, especially the coarse, nepheline syenites of Greenland; Kola, Russia; and in the augite syenites of Norway. It occurs also in the nepheline syenites of Dungannon township, Ontario, and of the Trans-Pecos district, Texas.

Riebeckite is also formed in acid rocks rich in soda, such as certain granites, syenites, etc. It is found on the Island of Socotra in the Indian Ocean; in fine-grained granitic rocks at Ailsa Crag, Scotland; in Corsica and a few other places. The crocidolite variety occurs in a clay slate on the banks of the Orange River in South Africa; at various points in the Vosges, Salzburg, Tyrol and Andalusia, in Europe; in Templeton, Ontario; in veins at Beacon Pole Hill, near Cumberland, R. I., in granites at Quincy and Cape Anne, Mass., near St. Peter's Dome, El Paso Co., Colorado, and as fibers in rocks at various other points in the United States.

TRICLINIC AMPHIBOLE

The only known triclinic amphibole is the comparatively rare **aenigmatite,** an alkali amphibole with a complicated composition that may be represented by the formula $Na_4Fe_9(Al \cdot Fe)_2(Si \cdot Ti)_{12}O_{38}$. The mineral occurs in very complex crystals, with $110 \wedge 1\bar{1}0 = 66°$, in alkaline rocks at Naujakasik, Greenland; in the Fourch Mts., Ark.; and at several other places.

It is black, or brownish black, and translucent or transparent and has a reddish brown streak. It is, moreover, strongly pleochroic in brownish black and reddish brown tints. It is brittle, has a hardness of a little more than 5 and a density of 3.7–3.8. Before the blowpipe it fuses to a brownish black glass. It is partly decomposed by acids. It is distinguished from other dark hornblendes by the cleavage angle of 66°.

BASIC METASILICATES

Kyanite ($(AlO)_2SiO_3$)

Kyanite, cyanite, or disthene, is a fairly common product of metamorphism in certain schists. The name kyanite suggests the sky blue color noticed in many specimens. The name disthene refers to the great difference in hardness exhibited in different directions.

The mineral is regarded as a basic metasilicate of the theoretical

composition: $SiO_2 = 37.02$; $Al_2O_3 = 62.98$ (compare pages 319, 320). Nearly all specimens contain a little Fe_2O_3 but otherwise they correspond very closely to the calculated composition indicated by the above formula. A light blue specimen from North Thompson River, B. C., upon analyses, gave:

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Total
36.29	62.25	.55	1.06	.36	100.51

Kyanite crystallizes in the triclinic system (triclinic pinacoidal class), with an axial ratio .8991 : 1 : .7090; $\alpha = 90° 5\frac{1}{2}'$, $\beta = 101° 2'$ and $\gamma = 105° 44\frac{1}{2}'$. Very few crystals are well developed. Their habit is columnar or tabular with $\infty P \bar{\infty}$ (100) predominating. More frequently the mineral occurs in long, flat, isolated blades, or in diverging flat plates (Fig. 210). Some crystals are very complex. Usually, however, only the forms $\infty P \bar{\infty}$ (100), $\infty P \breve{\infty}$ (010), $\infty P'$(110), $\infty 'P\bar{2}$(210), $\infty 'P(1\bar{1}0)$ and oP(001) are present. Twinning is common according to several laws, most of which, however, yield twins in which the basal planes (oP) of the twinned individuals are parallel. The most frequent twins have $\infty P \bar{\infty}$ (100) as the twinning plane. Other twinning planes are perpendicular to the axis *c*, or to the axis *b*. The basal plane oP(001) also serves as the twinning plane in some cases. Twinning is often repeated, producing lamellae crossing columnar crystals approximately parallel to the basal plane, and giving rise to a definite parting in this direction.

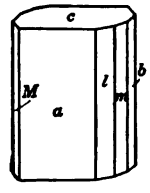


FIG. 210.—Kyanite Crystal with $\infty P \bar{\infty}$, 100 (*a*); $\infty P \breve{\infty}$, 010 (*b*); oP, 001 (*c*); $\infty 'P$, $1\bar{1}0$ (*M*); $\infty P'$, 110 (*m*) and $\infty P'2$, 210 (*l*).

The cleavage of kyanite is very perfect parallel to $\infty P \bar{\infty}$ (100) and less perfect parallel to $\infty P \breve{\infty}$ (010). It frequently possesses also a parting parallel to oP(001), as already stated. The luster on cleavage faces is pearly. Otherwise it is glassy. The mineral is often light blue in color, less frequently it is colorless or white, yellow, green, brown or gray. It is translucent or transparent and the darker blue varieties are pleochroic in dark and light blue tints. Its hardness varies greatly on different faces and in different directions on the same face. On the macropinacoid *a* it is about 5 parallel to the vertical edges, and 7 in the direction at right angles to this. The specific gravity of the mineral is about 3.6, and its refractive indices for yellow light are: $\alpha = 1.7171$, $\beta = 1.7222$, $\gamma = 1.7290$.

Before the blowpipe kyanite whitens, but otherwise it reacts like

sillimanite. It is insoluble in acids. It is distinguished from the few other minerals that it resembles by the great differences in hardness on its cleavage surfaces. At a high temperature (about 1350°) it apparently changes to sillimanite.

Kyanite weathers to muscovite, talc (p. 401) and pyrophyllite (p. 406), and is itself an alteration product of andalusite and corundum.

Synthesis.—It is not known that the mineral has been produced in the laboratory.

Occurrence and Origin.—Kyanite occurs as large plates and small

FIG. 211.—Bladed Kyanite Crystals in a Micaceous Quartz Schist from Pizzo Forno, Switzerland. (About natural size.)

crystals in micaceous and other schists (Fig. 211), and as an important constituent of some quartzites. At Horrsjöberg, in Wermland, Sweden, it forms a distinct layer of schist several meters thick. In a few places it is found in zones of contact metamorphism, but it is more frequently the result of dynamic metamorphism (cf. p. 26).

Localities.—Crystals have been found at Greiner in the Tyrol; at Mte. Campione in Switzerland; and at Graves Mt. in Lincoln Co., Ga. The mineral also occurs in fine plates at Chesterfield, Mass.; at Litchfield, Conn.; at Bakersville, N. C.; and on North Thompson River, B. C., Canada.

Uses.—Transparent kyanite is sometimes used as a gem.

Calamine ($(ZnOH)_2SiO_3$)

Calamine, or hemimorphite, is an important ore of zinc. It is one of the few silicates used as a source of metals. While theoretically a pure zinc compound it usually contains a little Fe_2O_3 and frequently small quantities of PbO. In some cases it contains also a little carbonate. A number of formulas have been suggested for it, of which the one given above is the simplest. According to several prominent mineralogists, however, the formula $Zn_2SiO_4 \cdot H_2O$ is preferable.

	SiO_2	Fe_2O_3	ZnO	H_2O	Total
Theoretical.....	25.01	....	67.49	7.50	100.00
Wythe Co., Va.....	23.95	....	67.88	8.13	99.96
Friedensville, Pa.....	24.32	2.12	65.05	7.89	99.38

The mineral occurs in brilliant crystals that are orthorhombic and distinctly hemimorphic (rhombic pyramidal class), with an axial ratio of .7834 : 1 : .4778. The crystals are usually tabular parallel to $\infty P\breve{\infty}$ (010). Many are highly modified but some are fairly simple, with ∞P(110), $\infty P\bar{\infty}$ (100) and $3P\bar{\infty}$ (301) in the prismatic zone, $3P\breve{\infty}$ (031), $P\bar{\infty}$ (101), $P\breve{\infty}$ (011) and oP(001) at the analogue pole and $2P\breve{2}(12\bar{1})$ at the antilogue pole (Fig. 212). The angle $110 \wedge 1\bar{1}0 = 76° 9'$. Twins are fairly common, with oP(001) the twinning plane. Often many crystals are grouped in sheaf-like, fibrous or warty aggregates and in crusts. The mineral is also granular and compact. Its cleavage is perfect parallel to ∞P(110).

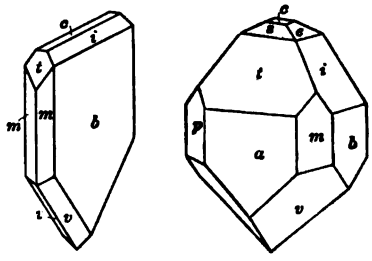


FIG. 212.—Calamine Crystals with ∞P, 110 (*m*); $\infty P\bar{\infty}$, 100 (*a*); $\infty P\breve{\infty}$, 010 (*b*); $2P\breve{2}$, $12\bar{1}$ (*v*); $P\bar{\infty}$, 101 (*s*); $P\breve{\infty}$, 011 (*e*); $3P\bar{\infty}$, 301 (*t*); $3P\breve{\infty}$, 031 (*i*) and oP, 001 (*c*).

Calamine is glassy, transparent or translucent, and when pure is colorless or white. Usually, however, it is gray, yellow, brown, greenish or bluish. Its streak is white, its hardness 4–4.5 and its density 3.2–3.5. It is brittle. Its fracture is uneven. The mineral is strongly pyroelectric with the end of the crystals terminated by dome faces the analogue pole. In contact twins both ends are analogues. The mineral becomes phosphorescent upon rubbing, and is fluorescent in ultra violet light. Its refractive indices for yellow light are: $\alpha = 1.6136$, $\beta = 1.6170$, $\gamma = 1.6360$.

Before the blowpipe calamine is almost infusible, but on charcoal it swells, colors the flame greenish and fuses with difficulty on the edges.

With soda it gives the zinc sublimate. In the closed glass tube it decrepitates and yields water and becomes cloudy. Its powder dissolves in even weak acids with the production of gelatinous silica.

Calamine is distinguished from *smithsonite* by its reaction with acids and from other minerals by its crystallization and reaction for zinc. It alters to willemite, smithsonite and quartz. Calamine has not been produced artificially.

Occurrence.—It occurs principally in the upper or oxidized zones of veins of zinc ore and in layers above the zone of permanent ground water in certain zinc and lead-bearing limestones. It is associated with lead ores and various zinc compounds, and it often pseudomorphs calcite, galena and pyromorphite.

Localities.—Calamine occurs in nearly all places where zinc and lead ores are found. It is abundant at Altenberg near Aachen in Rhenish Prussia; at Wiesloch, in Baden; near Tamowitz, in Silesia; at Rézbánya, Hungary; near Bleiberg, Carinthia; near Santander, Spain; in Cumberland, England; at Sterling Hill, N. J.; at Friedensville, near South Bethlehem, Penn.; at the Bertha Mine in Pulaski Co., and at the Austin Mine, in Wythe Co., Va.; and in the zinc-producing areas in the Mississippi Valley.

Uses.—It is a common associate of other zinc ores and many lead ores and is mined with the former as a source of zinc.

ACID METASILICATES

SERPENTINE GROUP

The serpentine group includes a large number of hydrous magnesium silicates that differ from one another mainly in the proportions of water present and in the ratio of silica to magnesia. None of them yields crystals, though their crystallization is thought to be monoclinic. All occur in dense fibrous or platy aggregates. The most prominent members of the group are:

		SiO_2	MgO	H_2O
Serpentine.....	$H_4Mg_3Si_2O_9$, or $H(MgOH)_3(SiO_3)_2$	=43.50	43.46	13.04
Meerschaum.....	$H_4Mg_2Si_3O_{10}$, or $H_3Mg(MgOH)(SiO_3)_3$	=60.83	27.01	12.16
Steatite.....	$H_2Mg_3(SiO_3)_4$	=63.52	31.72	4.76

All are soft and nearly infusible, and all are of considerable economic importance.

Serpentine ($H_4Mg_3Si_2O_9$)

The substance known as serpentine may be two different minerals, one orthorhombic and the other monoclinic. They, however, cannot be distinguished, except by microscopic study. Serpentine occurs in structureless, fibrous, foliated and schistose masses of a white, gray, brown or green color. It is translucent and has a dull, slightly glistening or fatty luster, and a white streak. The variety known as "noble serpentine" is nearly transparent and has a clear greenish or yellowish white, yellowish green, apple-green or dark green color. The mineral, when pure, has a hardness of 3, but it frequently seems harder because there are often mixed with it tiny remnants of the much harder minerals from which it was derived. The specific gravity of pure serpentine is 2.5–2.6. Its refractive indices vary widely. $\beta = 1.502–1.570$.

Serpentine fuses on thin edges when heated in the blowpipe flame. It yields water in the closed tube. When heated to about 1400° it crystallizes as olivine. It is decomposed by hydrochloric and sulphuric acids with the separation of gelatinous silica, which, in fibrous varieties, retains the shapes of the fibers. It is also soluble in dilute carbonic acid. Its powder reacts alkaline.

Chrysotile is a silky, nearly transparent fibrous variety occurring in veins. It is apparently orthorhombic.

Antigorite is a form occurring in laminated masses or in microscopic scales, that are possibly monoclinic.

Baltimorite and *picrolite* are coarse, green, fibrous varieties.

Analyses of a pure green serpentine, and a typical chrysotile, both from Montville, N. J., are quoted below:

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	H_2O	Total
I.	42.05	...	.30	.10	42.57	.05	14.66	99.73
II.	42.42	.63	.62	...	41.01	...	15.64	100.55

I. Green serpentine, Montville, N. J.
II. Chrysotile, Montville, N. J. Also .23 NiO.

Massive varieties are distinguished from *talc* by their solubility in acids and by differences in hardness, and chrysotile is distinguished from *amphibole* asbestus by the presence in it of water.

Synthesis.—Serpentine has been made by the action of a solution of Na_2SiO_3 upon magnesite for 10 days at 100°.

Occurrence.—The mineral is a common decomposition product of several other magnesium silicates, more particularly olivine, pyroxene

and chondrodite. Many igneous rocks rich in these minerals are completely changed to serpentine, especially around their peripheries, and some metamorphosed limestones are also partially or completely serpentinized. It is probably a secondary mineral in all cases.

Localities.—Serpentine occurs in large quantity at Webster, N. C.; Montville, N. J.; Easton, Penn.; at the Tilly Foster Iron Mine, Brewster, N. Y., at Thetford and Black Lake in the Eastern Townships of Quebec, and at many other places in North America. It is also known from many places in Europe.

Uses.—Serpentine when massive is used as a building stone. The finer varieties are sawed into thin slabs and used for ornamental purposes. Marble with streaks and spots of serpentine is known as *ophicalcite* and under the name "verd-antique" is employed as an ornamental stone. Mixtures of serpentine with other soft minerals are ground for a paper pulp. The fibrous variety—chrysotile—is mined and sold under the name of asbestos, which, because of its fibrous structure, its flexibility, its incombustibility, and because it is a nonconductor of heat and electricity is becoming an exceedingly important economic product. It is woven into paper and boards that are used to cover steam pipes, and to increase electric insulations, and is manufactured into shingles. It is used also in fireproofing, in the manufacture of automobile tires, in making paints, and as a substitute for rubber in packing steam pipes.

Preparation.—The chrysotile mined in Vermont comes from a mass of serpentine that is cut by many small veins of chrysotile. The rock is crushed and the fiber is separated by washing, or by some other mechanical method. The pulp rock at Easton is a mass of serpentine, talc and a few other minerals. It is ground and sized for use in paper manufacture.

Production.—Chrysotile is mined in Vermont and Wyoming. The production is rapidly increasing but the actual amount mined annually has not been disclosed. The total aggregate of chrysotile and amphibole asbestos (see p. 386), produced in the United States during 1912 was 4.403 tons, valued at $87,959. The imports of unmanufactured asbestos for the same year were valued at $1,456,012, of which $1,441,475 worth came from Canada. The total production of this country in the same year amounted to about $2,979,384, most of which came from the Thetford district in Quebec. This is about 80 per cent of the world's production. The value of the serpentine used as an ornamental and building stone is not known.

Garnierite

Garnierite may be regarded as a serpentine or talc in which a portion of the magnesium has been replaced by nickel, or possibly as a mixture of a colloidal magnesium silicate and a nickel compound. Its importance consists in the fact that it is the only commercial source of nickel aside from the pentlandite in the pyrrhotite of Sudbury, Canada. Three analyses of garnierite from New Caledonia follow:

SiO_2	NiO	MgO	$Al_2O \cdot Fe_2O_3$	H_2O	Total
35.45	45.15	2.47	.50	15.55	99.12
37.78	33.91	10.66	1.57	15.83	99.75
42.61	21.91	18.27	.89	15.40	99.08

These show that as MgO diminishes, NiO increases.

Garnierite is a dark green to pale green substance with many of the physical properties of serpentine. Its luster is dull, or like that of varnish. It has a greasy feel, a hardness of 2–3 and a density of 2.3–2.8. Its streak is light green to white. When touched to the tongue it adheres like clay. It is infusible when heated before the blowpipe, but decrepitates and becomes magnetic. It is partly soluble in HCl and HNO_3.

It is readily distinguished from *malachite* and *chrysocolla* by its structure, its greasy feel and the absence of a good copper test.

Occurrence and Localities.—The mineral occurs as earthy masses, as mamillary coatings and as impregnations and veins in serpentine. In all cases it appears to have resulted from the weathering of peridotite. The earthy masses are residual and the veins are deposits from downward percolating water that obtained nickel from the decomposing rock.

The principal occurrences of garnierite are New Caledonia, where it is mined as a source of nickel, and at Riddles, Douglas Co., Oregon. A very closely allied species, *genthite*, occurs associated with chromite in serpentine at Texas, Lancaster Co., Penn., at Webster, N. C., at Malaga, in Spain, and at a few other places.

Production.—Garnierite is mined from 40 mines on the plateau of Thio, New Caledonia, at the rate of about 130,000 tons annually of a 6½ per cent ore. In 1912 there were produced 72,315 tons of ore and 5,097 tons of matte containing 2,263 tons of nickel. The aggregate value of ore and matte was about $1,140,000.

Meerschaum ($H_4Mg_2Si_3O_{10}$)

Meerschaum, or sepiolite, occurs as a massive, dense, earthy aggre gate of a white, yellowish or reddish color, and also as a finely fibrous, crystalline aggregate (*parasepiolite*). It is opaque, has a conchoidal fracture and a shining white streak. Its hardness is 2 and density about 2. Dry specimens will float on water, because they are not easily wet. When touched to the tongue a clinging sensation is produced. Two varieties of the commercial material have been recognized. Of these, one, α sepiolite, is $H_8Mg_2(Si_3O_{12})$ and the other β sepiolite, has the composition indicated above.

The analyses of white meerschaum rrom Asia Minor and from Utah gave the following results:

	SiO_2	Al_2O_3	Fe_2O_3	MgO	H_2O	Total
Asia Minor..	52.45	.80	...	23.25	23.50	100.00
Utah.....	52.97	.86	.70	22.50	18.70 *	99.74

* Of this 8.80% was driven off at 100°. Included also are 3.14 Mn_2O_3 and .87 CuO.

Before the blowpipe the mineral fuses on its edges to a white enamel. Often, at first, it turns brown or black and then, upon higher heating, it bleaches to white. At low temperature in the closed tube it yields a little hygroscopic water. At high temperature water is given off freely. The mineral dissolves in hydrochloric acid, with the production of gelatinous silica in the case of the α variety.

Meerschaum resembles chalk and kaolin, from which it is easily distinguished by treatment with hydrochloric acid.

Occurrence and Localities.—The mineral is found as nodules in young sedimentary beds in Asia Minor, where it is associated with magnesite. Both minerals are believed to be alteration products of serpentine. It occurs also with opal at Thebes, Greece. A red variety occurs in limestone at Quincy, France, and a green and white variety forms a small vein in a silver ore in Utah. In all of its occurrences it seems to be secondary.

Uses.—Meerschaum is used for carving into ornaments and pipes.

Steatite ($H_2Mg_3(SiO_3)_4$)

Steatite, or talc, usually occurs in flaky, foliated and massive forms, and in plates that appear to be tabular crystals with hexagonal outlines. It also forms, with chlorite and a few other substances, the rock soapstone. Although its crystallization is unknown, because of the close

analogy between its physical properties and those of chlorite and the micas its symmetry is believed to be monoclinic.

The composition of pure white talc and ordinary soapstone are shown by the two analyses below:

	White talc Urserenthal, Switzerland	Soapstone W. Griqualand, Africa
SiO_2	60.85	63.29
Al_2O_3	1.71	1.24
Fe_2O_3	.....	.16
FeO	.09	4.68
MgO	32.08	27.13
H_2O	4.95	4.40
Total	99.68	100.90

The composition corresponding to the formula $H_2Mg_3(SiO_3)_4$ is: $SiO_2=63.5$, $MgO=31.7$ and $H_2O=4.8$.

The cleavage of talc is well marked and on its cleavage surfaces its luster is pearly. Its cleavage plates are flexible. The mineral is white, gray, greenish or bluish, and is transparent or translucent. The massive forms, known as soapstone, are white, greenish, yellowish, red or brown. All varieties are soft—the mineral being chosen to represent 1 in the scale of hardness—and all have a soapy feeling. The density of pure talc is 2.6–2.8. For yellow light, $\alpha=1.539$, $\beta=1.589$, $\gamma=1.589$.

Before the blowpipe the mineral exfoliates, hardens and glows brightly, but it is nearly infusible (fusing temperature is about 1530°), melting only on the thinnest edges to a white enamel. It yields water in the closed tube only at a high temperature. It is unattacked by acids before and after heating. Its powder reacts alkaline.

It is distinguished from other white, soft minerals by its softness, its insolubility in acids and its infusibility.

Occurrence.—The mineral is a common alteration product of other magnesium silicates, often pseudomorphing them. Thus, pseudomorphs of the mineral after actinolite, bronzite and sahlite are common. Pseudomorphs after pectolite, dolomite and quartz are also known. In these forms it is secondary.

It occurs also in marbles and other crystalline rocks, where it was produced by regional metamorphism. It is found, further, as small veins cutting serpentine and metamorphosed limestones, as layers under the name of talc schists, associated with other schistose rocks and as massive aggregates of finely matted fibers, probably resulting from the alteration of basic igneous rocks. The last described variety is the rock soapstone.

The vein material is usually white, fibrous and pure. It is ground and placed on the market as talc. The impure variety (soapstone) is sawn into blocks and boards.

Localities.—Talc and soapstone occur at many places. Good white platy talc occurs at Lampersdorf, in Silesia; near Pressnitz, in Bohemia; near Mautern, in Steiermark; at Andermatt, in Switzerland; at Russell, Gouverneur and other points in New York; at Webster, N. C.; and at Easton, Penn.

Uses.—Ground talc is extensively used as a lubricator, in the manufacture of paper, as a filler in curtains, cloth, etc., as a foundry facing, in the manufacture of molded rubber goods, as a toilet powder, as a polishing material, as a pigment, in the manufacture of gas tips, pencils, crayons, etc. Soapstone is sawn and used as linings of acid vats and laundry tubs, and in the manufacture of table tops, sinks, etc., in chemical laboratories. Because of its nonabsorbent qualities it is also being used largely in electric switchboards. Its various uses are due to its softness, infusibility, and its power of resistance to the attacks of acids.

Production.—The principal sources of talc and soapstone in the United States are in a belt on the east side of the Appalachians extending from Vermont to Georgia. Largest producers in 1912 were:

Virginia, with a production of 25,313 tons, valued at $576,473,
New York, with a production of 66,867 tons, valued at $656,270,
Vermont, with a production of 42,413 tons, valued at $275,679.

Of the aggregate of 159,270 tons, valued at $1,706,963 produced in 1912, 15,510 tons were sold in the rough for $66,798; 2,642 tons, sawed into slabs, were sold for $50,334, 21,557 tons were manufactured and sold for $600,105, and 119,561 tons were sold ground for $989,726. Of this aggregate 133,289 tons, valued at $1,097,483 were talc and 25,981 tons, valued at $609,480 were soapstone. In addition to the home production, there were also consumed in the United States 10,989 tons of high-grade talc, valued at $122,956, which was imported.

KAOLINITE GROUP

The kaolinite group of minerals comprises hydrous aluminium silicates corresponding to the magnesium silicates of the serpentine group. The principal members of the group are:

Kaolinite,	$H_4Al_2Si_2O_9$, or	$H_2Al(Al(OH)_2)_3(SiO_3)_4$
		$=46.50\ SiO_2,\ 39.56\ Al_2O_3,\ 13.94\ H_2O$
Pyrophyllite,	$H_2Al_2(SiO_3)_4$	$=66.65\ SiO_2,\ 28.35\ Al_2O_3,\ 5.00\ H_2O$

Kaolinite corresponds to serpentine in which all the Mg has been replaced by Al and pyrophyllite to steatite. In addition to these, there are other closely related compounds which may be intermediate in composition between these two. Among them the most common are *allophane*, *montmorillonite* and *halloysite*.

Both minerals are of economic importance. Kaolinite is the base of all clay products like pottery, tile, bricks, etc.

Kaolinite ($H_4Al_2Si_2O_9$)

The crystallization of kaolinite is probably monoclinic. The crystals, which are rare, are thin plates with an hexagonal habit, bounded by the planes oP(001), ∞P(110) and ∞P$\bar{\infty}$(010) and +P($\bar{1}$11). Their axial ratio is .5748 : 1 : 1.5997 with $\beta = 83° 11'$. Their cleavage is perfect parallel to the base.

Distinct crystals have been found only on the Island of Anglesey, Wales, and at the National Belle Mine, at Silverton, Colo., where they comprise a white powder every grain of which is a crystal.

The mineral, when pure, is white or colorless and transparent. It has a hardness of 1 and a specific gravity of 2.45. It is infusible before the blowpipe and is only slightly attacked by HCl. It is decomposed by alkalies and alkaline carbonates with the production of hydrated silicates. Its index of refraction is about 1.56.

The greater part of the kaolinite known is not in crystals. It usually occurs in foliated or dense earthy masses to which various names have been assigned.

Nakrite is a white crystalline mass of kaolinite made up of tiny flakes often arranged in fan-like or divergent groups. The individual flakes have a pearly luster. It occurs as vein fillings in certain ore-bodies.

Steinmarkite is a dense mass of microscopic grains often forming nodular masses and occurring as veins and nests in rocks. It is harder than pure kaolin (H = 2–3), and is often yellowish, gray or red in color.

Kaolin is an earthy, friable mass of flaky kaolinite which when moist becomes plastic, and, therefore, of great value in the manufacture of pottery. It is more soluble in acids than the crystallized variety. It fuses at about 1780°.

Kaolin is distinguished from *chalk* by its reaction toward HCl, from *meerschaum* and *talc* by the reaction for Al with $Co(NO_3)_2$, and from *infusional earth* by the fact that its powder will not scratch glass.

Clay is a mixture of kaolinite, quartz, fragments of other mineral

particles and various decomposition products of kaolinite and other silicates, among the most important being various colloidal, hydrous, aluminous silicates and magnesium and calcium carbonates. The greater the proportion of colloidal material in the clay the more plastic it is and the more valuable for manufacturing purposes. Different clays have received different names which indicate in a way their uses. Among the most important of these are:

China clay, a very pure, white kaolin,
Ball clay, a white, very plastic clay,
Fire clay, a fairly pure clay capable of resisting great heat,
Flint clay, a hard clay which is not plastic even after grinding,
Brick clay, an impure clay suitable for making brick,
Pottery clay, *stoneware clay*, *terra-cotta clay*, etc., are all impure clays that are adapted to the uses suggested by their names.

Sample analyses of kaolinite and of some of the purer clays follow:

	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	H_2O	F	Total
I.	46.35	39.59	.11	.15	...	13.93	.15	100.13
II.	46.86	39.24	....	....	...	13.90	...	100.00
III.	43.46	41.48	....	1.20	.37	13.49	...	100.00
IV.	59.92	27.56	1.03	tr.	.64 *	10.82	...	99.97

I. Crystals from National Belle Mine, Colo.
II. Kaolin, Seilitz, near Meissen, Saxony.
III. Steinmarkite, Schlaggenwald, Bohemia.
IV. Flint fire clay, Salineville, Ohio.

* Na_2O+K_2O.

Occurrence.—Kaolinite occurs in feldspathic rocks near ore veins. Here it was formed partly by ascending magmatic solutions and partly by descending H_2SO_4, produced by the oxidation of the sulphides in the upper portions of the veins. Most kaolin, however, is a weathering product of feldspar (see p. 408), and of feldspathic rocks. When acted upon by water, and more particularly by water containing dissolved CO_2, the feldspars lose alkalies, calcium and some silica, leaving an aluminium silicate behind. Thus, for the potash feldspar orthoclase:

$K_2O \cdot Al_2O_3 \cdot 6SiO_2 (= KAlSi_3O_8) - K_2O \cdot 4SiO_2 = Al_2O_3 \cdot 2SiO_2$, which with $2H_2O = H_4Al_2Si_2O_9$ (kaolinite).

Other silicates also yield kaolinite on weathering—in some cases completely changing so as to yield pseudomorphs of kaolin.

Very complete weathering of this kind takes place in bogs, and

some of the best known beds of kaolin are believed to have been formed at the bottoms of peat bogs.

Localities.—Kaolinite in measurable crystals occurs only at the two localities that have already been mentioned. The pure, white, dense kaolin is fairly widely spread. Clay occurs almost universally. The principal localities of kaolin in North America are near Jacksonville, Ala.; Mt. Savage, Md.; various points in Tennessee, North Carolina, Illinois, Missouri, New Jersey and Pennsylvania.

Production.—The total value of clay products manufactured in the United States during 1912 was over $172,800,000, of which by far the largest part is represented by common brick, of which $51,796,000 worth were made. Pottery followed with an output valued at $36,504,000. It is not possible to estimate the value of the clay represented in the manufactured product because in most cases the manufacturers mine their own clay and make no account of the raw material. The quantity of clay mined in the United States and sold to manufacturers during 1912 amounted to 2,530,000 tons, valued at $3,946,000. In addition, there were imported 334,655 tons of clay, valued at $1,952,000.

Pyrophyllite ($H_2Al_2(SiO_3)_4$)

Pyrophyllite nearly always occurs in groups of radiating or diverging fibers that are either orthorhombic or monoclinic in crystallization. It may be isomorphous with steatite. The bundles of fibers cleave easily into flexible sheets that have a pearly luster on their cleavage faces. When pure the mineral is light-colored in shades of yellow, gray or green. It is transparent or translucent and has a greasy feel. Dense, structureless masses are known as *agalmatolite.*

The mineral is very soft, about 1. Its density is 2.8 or 2.9. Before the blowpipe it melts on the edges to a white enamel and fibrous varieties exfoliate and swell. Heated in the closed tube pyrophyllite assumes a silvery luster and gives off water. It is only partially soluble in HCl, but is completely decomposed by Na_2CO_3.

It is best distinguished from *talc* by the reaction for aluminium.

Synthesis.—Upon heating to 300°–500° a mixture of SiO_2,Al_2O_3 and potassium silicate a mass is obtained which consists of andalusite, muscovite and pyrophyllite.

Occurrence and Localities.—Pyrophyllite is found at a number of points in many different associations, where it is probably the result of weathering of other silicates. Its principal localities in the United States are Graves Mt., Ga.; Cotton Stone Mt., Deep River, Car-

bonton and Glendon, N. C.; Chesterfield, S. C.; and Mahanoy City, Penn.

Uses.—The massive form of the mineral is used to some extent in making slate pencils, and for the other purpose for which talc is employed. Agalmatolite is used by the Chinese as a medium from which they carve small images.

CHAPTER XVIII

THE SILICATES—*Continued*

THE ANHYDROUS TRIMETASILICATES

THE FELDSPARS

THE feldspars are among the most important of all minerals. They are abundant as constituents of many igneous rocks and in mixtures filling veins. Their principal scientific importance lies in the fact that they indicate by their composition the nature of the rock magmas from which they crystallize. Consequently, in some systems of rock classification the grouping of the rocks is based primarily upon the presence or absence of feldspar, and the naming of the feldspathic rocks is in accordance with the nature of their most prominent feldspathic constituent. Moreover, some of the feldspars are of economic importance.

Chemically, the feldspars may be regarded as isomorphous mixtures of the four compounds, $KAlSi_3O_8$, $NaAlSi_3O_8$, $Na_2AlAlSi_2O_8$, $CaAlAlSi_2O_8$ and $BaAlAlSi_2O_8$, each of which, except the third, has been found nearly pure in nature as *orthoclase* and *microcline*, *barbierite* and *albite*, *anorthite* and *celsian*. The third, $Na_2AlAlSi_2O_8$, has been made in the laboratory, but it occurs in nature only in isomorphous mixtures with the anorthite and albite molecules. The pure compound has been called *carnegieite* and its mixtures *anemousites*. The feldspars have also been regarded as salts of the acid $H_5AlSi_2O_8$ in which the hydrogen is replaced by various radicals, thus: $(KSi)AlSi_2O_8$, orthoclase; $(NaSi)AlSi_2O_8$, albite; $(CaAl)AlSi_2O_8$, anorthite, and $(BaAl)AlSi_2O_8$, celsian.

The potash molecule crystallizes from magmas containing potassium, sodium and calcium, but it also frequently forms isomorphous mixtures with the soda molecule and in some cases with the barium molecule. Mixtures of the potash and calcium molecules are extremely rare as minerals, but they have been formed experimentally in the laboratory. The albite and the calcium molecules are usually intermixed. Both are known in a nearly pure condition as minerals, but their mixtures are much more common. Indeed they are so common that they are separated from the other feldspars and formed into a dis-

tinct subgroup under the name of the *plagioclase* group, with albite and anorthite as the two end members. The plagioclases constitute the best known isomorphous series of compounds in the realm of mineralogy.

The calculated compositions of pure orthoclase (or microcline), albite, anorthite and celsian with their specific gravities are:

	SiO_2	Al_2O_3	K_2O	Na_2O	CaO	BaO	Sp. Gr
Orthoclase..	64.7	18.4	16.9	....	....	....	2.55
Albite.....	68.7	19.5	....	11.8	....	....	2.61
Anorthite...	43.2	36.7	....	....	20.1	....	2.76
Celsian.....	32.0	27.2	....	....	....	41.8	3.34

All the feldspars are triclinic, but the pure potassium and sodium compounds, in addition to possessing distinct triclinic phases (microcline and albite) occur also in crystals which, because of sub-microscopic twinning, (p. 420) are apparently monoclinic (orthoclase and barbierite). Usually the forms on orthoclase are designated by symbols that refer to the monoclinic axes, but since the habits of all feldspars are the same they can be as readily understood when referred to the triclinic axes. The crystallographic constants for the members of the group that consist of unmixed molecules are:

	a	*b*	*c*	α	β	γ	Angle(001)∧(010)
Orthoclase..	.6585	: 1 :	.5554	90°	116° 3′	90°	90°
Microcline..							89° 30′
Celsian.....	.657	: 1 :	.554	90°	115° 2′	90°	90°
Albite.....	.6335	: 1 :	.5577	94° 3′	116° 29′	88° 9′	86° 24′
Anorthite.....	.6347	: 1 :	.5501	93° 13′	115° 53′	91° 12′	85° 50′

The simple crystals of feldspar exhibit three habits, but on nearly all the same forms occur. These are oP(001), $\infty P\breve{\infty}$ (010), $\infty P'$(110), $\infty{}'P(1\bar{1}0)$, $_{,}P_{,}\bar{\infty}$ $(\bar{1}01)$, $2_{,}P_{,}\bar{\infty}$ $(\bar{2}01)$ and less commonly $2_{,}P'\breve{\infty}$ (021), $2'P_{,}\breve{\infty}$ $(0\bar{2}1)$, $\infty P_{,}'\breve{3}(130)$, $\infty{}_{,}'P\breve{3}(1\bar{3}0)$, $_{,}P(\bar{1}11)$, $P_{,}(\overline{1}\overline{1}1)$ and $\infty P\bar{\infty}$ (100). In orthoclase and the other apparently monoclinic forms these symbols may be written oP, $\infty P\breve{\infty}$, ∞P, $P\bar{\infty}$, $2P\bar{\infty}$, $2P\breve{\infty}$, $\infty P\breve{3}$, P and $\infty P\bar{\infty}$ (Figs. 213 and 214). There have, moreover, been reported on orthoclase about 90 other planes and on the plagioclases about 45. Of these, however, a number are probably vicinal, as they have extremely large indices.

The principal habits are the equidimensional, the columnar (Fig. 213), and the tabular (Fig. 214). The tabular crystals are usually flattened parallel to 010. The columnar forms are elongated parallel to the *c* or the *a* axes.

Twinning is common, according to five laws, and much less common according to several others. Of the five common laws three apply to all the feldspars, and the remaining two to the triclinic types alone. The first three are the Carlsbad, the Manebach and the Baveno. The other two are the albite and the pericline.

In Carlsbad twins, 100 is the twinning plane and usually 010 is the

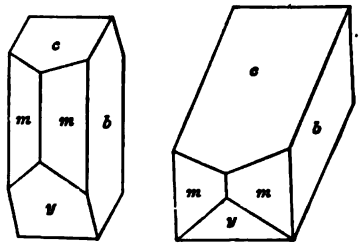


FIG. 213.

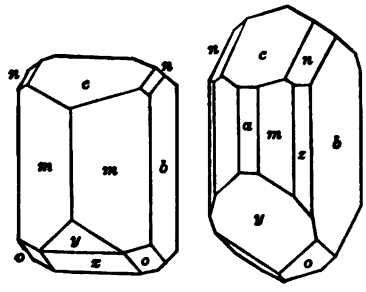


FIG. 214.

FIG. 213.—Orthoclase Crystals with ∞P, 110 (*m*); ∞P$\bar{\infty}$, 010 (*b*); 0P, 001 (*c*) and 2P$\bar{\infty}$, $\bar{2}$01 (*y*).

FIG. 214.—Orthoclase Crystals with *m*, *b*, *c* and *y* as in Fig. 213. Also P$\bar{\infty}$, $\bar{1}$01 (*x*); P, $\bar{1}$11 (*o*); ∞P3, 130 (*z*) and 2P$\bar{\infty}$, 021 (*n*).

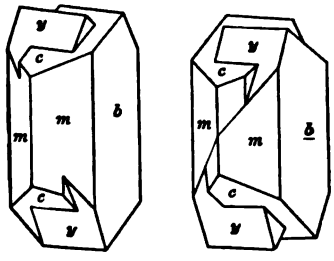


FIG. 215.

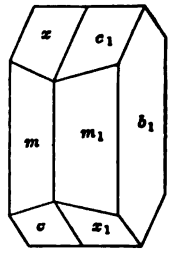


FIG. 216.

FIG. 215. Carlsbad Interpenetration Twins of Orthoclase. Twinning plane is ∞P$\bar{\infty}$ (100); composition face ∞P$\bar{\infty}$ (010).

FIG. 216.—Contact Twin of Orthoclase According to the Carlsbad Law.

composition face. The twinned parts may interpenetrate, as is usually the case (Fig. 215), or they may lie side by side forming a contact twin (Fig. 216). If in the contact twins the planes $\bar{1}$01 and 001 are equally prominent, since they are nearly equally inclined to the *c* axis the twin may be mistaken for a simple crystal (Fig. 216). In rare cases the composition face is 100 and the twinned parts are in contact.

The Baveno twins are contact twins, with 021 the twinning and composition planes (Fig. 217). As the individuals are elongated parallel to the *a* axis the result of the twinning is a square prism with its ends crossed by a diagonal that separates the same forms on the two twinned individuals. In some cases the twinning is repeated and a fourling results.

In Manebach twins, the twinning and composition plane is 001. These usually occur in columnar crystals elongated parallel to *a*, or in tabular crystals flattened parallel to 001 or 010 (Fig. 218).

Carlsbad, Baveno and Manebach twins, as has been stated, are common to feldspars of both the monoclinic and triclinic phases, but the pericline and albite laws are found only in the triclinic types. The

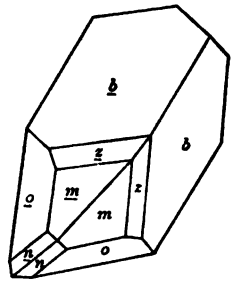


FIG. 217.

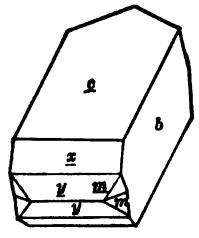


FIG. 218.

FIG. 217.—Baveno Twin of Orthoclase. Twinning and composition plane, 2P $\bar{\infty}$ (021).
FIG. 218.—Manebach Twin of Orthoclase. Twinning and composition plane, oP(001).

description of these is, therefore, deferred until the plagioclases are discussed.

Besides occurring in crystals, nearly all the feldspars are known also in granular and platy masses.

The pure feldspars are colorless and transparent or translucent, and all have a glassy luster which, on cleavage faces sometimes approaches pearly. As usually found, the feldspars are white, pink, reddish, yellowish, gray, bluish or green. Some specimens show a bluish white shimmer or opalescence (moonstone), and others a reddish sparkle (sunstone), due to enclosures of other minerals or of lamellae of a different refractive index from that of the main portion of the mass. All have a white streak. All possess a very perfect cleavage parallel to the base (001) and a scarcely less perfect one parallel to 010. Their fracture is uneven to conchoidal, and hardness 6.

Before the blowpipe fragments of the potash, barium, and calcium

feldspars are very difficultly fusible on their edges to a porous glass. The soda feldspars are a little more easily fusible. The fusing temperature of albite is between 1200° and 1250°, that of orthoclase approximately 1300°, and that of anorthite 1532°. Anorthite is soluble in hydrochloric acid with the production of gelatinous silica. The other three feldspars are insoluble.

The feldspars are distinguished from other minerals by their crystallization, their two nearly perfect cleavages approximately perpendicular to one another, and their hardness. They are distinguished from one another by characters that will be indicated in the descriptions of the several varieties.

Feldspars rich in orthoclase and soda weather fairly readily to muscovite, or kaolin and quartz. The soda feldspars in some cases change to zeolites (p. 445). With the addition of the calcium molecule calcite is often found in the weathering products. Under certain conditions, especially when in rocks containing magnesium and iron minerals, the calcium feldspars often change to a mixture of zoisite and albite, or a mixture of these with garnet, chlorite (p. 428), epidote and other compounds. This mixture is often designated by the name *saussurite.*

Syntheses.—All crystals of the feldspars, except those of pure albite and pure orthoclase (including microcline), have been made by slowly cooling a dry fusion of their components in open crucibles. Albite and orthoclase have been produced from similar fusions to which tungstic acid, alkali-tungstates or phosphates, or alkali-fluoride have been added. They have also been produced with quartz by fusion in the presence of moisture in closed tubes.

Occurrence and origin.—All except the barium feldspars occur as important constituents of most igneous and of many metamorphic rocks. They occur also abundantly in a few sandstones (arkoses) and in a few water-deposited veins, and are found around a few volcanic craters as products of gaseous exhalations. The barium feldspars are rare. They have been seen only in dolomite associated with barite and tourmaline, in manganese ores and manganese epidote; and intergrown with albite in a pegmatite at Blue Hill, Delaware Co., Pa.

With respect to origin feldspars may be primary separations from a magma, primary deposits from solutions, pneumatolytic deposits, or they may be the result of metasomatic process. They are common products of contact and regional metamorphism.

Uses.—The feldspars, though extremely abundant, have comparatively few uses. In the future the potash varieties may become a source of the potash salts used in the manufacture of fertilizers. At

present the principal use of the feldspars is in the manufacture of porcelain and other white pottery products and enamel ware. They are used as fluxes to bind together the grains of emery and carborundum in the making of grinding and cutting wheels, and are employed also in the manufacture of opalescent glass, artificial teeth, scouring soaps and "ready roofing."

Production.—All the feldspar used in commerce comes from pegmatites. The total quantity produced for all purposes in the United States during 1912 amounted to 86,572 tons, valued at $520,562. Of this, 26,462 tons were sold crude at a value of $89,001 and the balance ground. The principal varieties mined are orthoclase, microcline and albite, though oligoclase (a plagioclase rich in soda) is mined in small quantity.

ALKALI FELDSPARS

Orthoclase and Microcline ($KAlSi_3O_8$)
Barbierite and Albite ($NaAlSi_3O_8$)

Orthoclase and microcline have the same chemical composition. Both are potash feldspars, but both may contain sodium. On the other hand barbierite and albite are both essentially soda feldspars but both usually contain some potassium. In orthoclase the sodium is due to the admixture of the barbierite molecule, and in microcline to the presence of the albite molecule. The soda-rich microcline is generally known as *anorthoclase*. The pure barbierite is not known to exist as a mineral. Analyses of these four varieties follow:

	SiO_2	Al_2O_3	CaO	K_2O	Na_2O	H_2O	Total
I.	63.80	21.00	....	13.80	.....	1.40	100.00
II.	65.23	19.35	.76	9.31	4.52	.27	100.00
III.	67.00	19.12	.78	1.15	11.74	....	99.79
IV.	66.18	19.52	.36	13.03	.91	....	100.00
V.	67.99	19.27	.75	3.05	6.23	.90	99.03
VI.	68.28	19.62	.31	.39	10.81	.09	99.82

I. Orthoclase, Adularia, Elba.
II. Soda-orthoclase, Drachenfels, Prussia. Also .56 BaO.
III. Barbierite, Kragerö, Norway.
IV. Microcline, Ersby, Pargas, Finland.
V. Anorthoclase, from granite, Kekequabic Lake, Minn. Also .82 Fe_2O_3 and trace of MgO.
VI. Albite, from litchfieldite, Litchfield, Maine. Also .23 FeO and .09 MgO.

Albite is described among the plagioclases (p. 418).

The most noticeable difference between orthoclase and microcline is that the latter shows clearly its triclinic symmetry by its twinning,

FIG. 219.—Section of Microcline Viewed between Crossed Nicols. The grating structure indicates twinning. (*After Rosenbusch.*)

and its optical properties, while in orthoclase the twinning is so minute as to be unobservable and the optical properties are similar to those of monoclinic crystals. This difference is best exhibited in thin sections when viewed in polarized light under the microscope. Under these conditions certain sections of microcline exhibit series of light and dark bars crossing one another perpendicularly (Fig. 219), while sections of orthoclase do not. The grating structure is due to repeated twinning according to the albite and pericline laws at the same time (p. 419). If this method of twinning is present in orthoclase the lamellae are so minute that they cannot be seen even under high powers of the microscope.

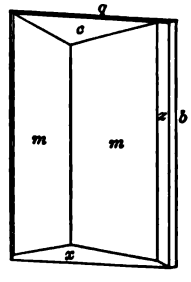


FIG. 220.—Adularia Crystal with *m*, *b*, *c*, *z* and *x* as in Figs. 213 and 214. Also $\frac{3}{2}P\,\bar{\infty}\,,\,\bar{2}03$ (*q*).

Several names that refer to more or less distinct varieties of the potash feldspars are in common use. The most important are:

Adularia, a nearly pure orthoclase, that is nearly transparent, occurring in veins. Its crystals have the characteristic habit illustrated in Fig. 220.

Sanidine, a glassy soda orthoclase, occurring as large crystals often flattened parallel to 010, embedded in lavas.

Moonstone, a translucent adularia, exhibiting a pearly luster, with a very slight play of colors.

Sunstone, a translucent variety exhibiting reddish flashes from inclusions of mica, or other platy minerals.

Perthite, parallel intergrowths of thin lamellae of orthoclase and albite.

Microcline-perthite, parallel intergrowths of lamellae of microcline and albite.

Orthoclase and the other pseudomonoclinic feldspars may be distinguished from the distinctly triclinic forms by the value of the cleavage angle which in orthoclase is 90°, and in the triclinic forms about 86°, except in microcline. (See p. 409.) The value of the angle $110 \wedge 1\bar{1}0 = 61° \; 13'$ in orthoclase. Its refractive indices for yellow light are: $\alpha = 1.519$, $\beta = 1.524$, $\gamma = 1.526$. With the admixture of the albite molecule these values increase. The sp. gr. of pure orthoclase is 2.55 and its fusing point a little higher than that of albite (see p. 412).

Orthoclase may be distinguished from the other pseudomonoclinic feldspars by its specific gravity and the flame reaction.

Syntheses.—Crystals of orthoclase have been made by fusing SiO_2 and Al_2O_3 with potassium wolframate, vanadate or phosphate. Also by heating aluminium silicate with a solution of potassium silicate and KOH in a tube at 100°, and by heating muscovite in a solution of potassium silicate at 600°.

Occurrence.—The potash feldspars are essential constituents of the igneous rocks—granite, syenites, rhyolites and trachytes—and of some crystalline schists, and are accessory components of a number of other rocks. They occur in most pegmatite dikes and as gangues in some ore veins, and in many contact metamorphosed rocks.

Localities.—The potash feldspars are so widely spread that an enumeration of their important occurrences is here impossible. The best known localities of orthoclase are Cunnersdorf, Silesia; Drachenfels and Lake Laach, Rhenish Prussia (sanidine); in the Zillerthal, Tyrol (adularia); at St. Gothard in the Alps (adularia); at Baveno, Italy, and at Mt. Antero, Chaffee Co., Col. Microcline crystals are well developed at Striegau, Silesia; in the pegmatite dikes of southern Norway; and at Pike's Peak, Col. (*amazonite*). Anorthoclase occurs at Tyveholmen and other points in Norway and in the lava of Kilimandjaro, Africa, and in that on Pantelleria, an island near Sicily. In North America pegmatites are abundant in southeastern Canada, in

New England and in the Piedmont plateau area immediately east of the Appalachian Mts., and throughout this district all forms of the opaque potash feldspars are abundant. Soda-potash feldspars have been described from many places, but whether they are soda orthoclase or anortholcase has rarely been determined.

All phases of the alkali feldspars occur as components of igneous and metamorphic rocks.

POTASH-BARIUM FELDSPARS

The feldspars containing potassium and barium comprise an isomorphous series with orthoclase and celsian as the two end members as follows:

		Sp. Gr.
Orthoclase (Or)	$KAlSi_3O_8$	2.55
Barium orthoclase	$Or_{19}Ce_1 - Or_{10}Ce_1$	2.593–2.645
Hyalophane	$Or_4Ce_1 - Or_7Ce_{31}$	2.725–2.818
Celsian (Ce)	$BaAl_2(SiO_4)_2$	3.384

The chemical composition of some of the barium feldspars are illustrated by the analyses quoted below:

	SiO_2	Al_2O_3	BaO	CaO	MgO	K_2O	Na_2O	H_2O	Total
I.	51.68	21.85	16.38	....	....	10.09	....	...	100.00
II.	52.67	21.12	15.05	.46	.04	7.82	2.14	.58	99.88
III.	53.53	23.33	7.30	....	3.23	11.71		...	99.10
IV.	54.15	29.60	1.26	1.00	1.52	12.47		...	100.00

I. Theoretical for Or_2Ce_1.
II. Binnenthal, Tyrol.
III. Jakobsberg, Sweden.
IV. Sjögrufran, Sweden.

The minerals are isomorphous with orthoclase (with the possible exception of celsian, which may exhibit the triclinic habit and may more properly be isomorphous with microclinic), and their axial constants are intermediate between those of orthoclase and celsian. The axial ratio for hyalophane is .6584 : 1 : .5512. $\alpha=90°$, $\beta=115°\ 35'$, $\gamma=90°$. Its cleavage angles are 90°. Its crystals, as a rule, have the adularia habit. The Indices of refraction of the barium feldspars are:

		α	β	γ
Barium-orthoclase	($Or_{19}Ce_1$)	1.5201	1.5240	1.5257
Hyalophane	(Or_1Ce_1)	1.5373	1.5395	1.5416
Hyalophane	(Or_7Ce_3)	1.5419	1.5419	1.5469
Celsian		1.5837	1.5886	1.5940

These feldspars are rare. They have been found only in metamorphosed dolomites in the Binnenthal, Valais; at the manganese mines at Jakobsberg and Sjögrufran, Sweden; and intergrown with albite in a pegmatite at Blue Hill, Delaware Co., Penn.

SODA-LIME FELDSPARS

Plagioclase is the general name given to the group of isomorphous feldspars of which albite and anorthite are the end members. The albite and anorthite molecules are isomorphous in all proportions and the physical properties of the mixed crystals accord completely with their composition. Certain mixtures are much more common than others. These were given individual names before it was recognized that they were merely members of an isomorphous series and these names were later applied to mixtures of definite compositions. The names and the compositions of the mixtures corresponding to them are given in the following table.

		SiO_2	Al_2O_3	Na_2O	CaO	Sp. Gr.
Albite	$NaAlSi_3O_8$(Ab)	68.7	19.5	11.8	....	2.605
Oligoclase	Ab_6An_1	64.9	22.1	10.0	3.0	
	Ab_3An_1	62.0	24.0	8.7	5.3	2.649
Andesine	Ab_3An_1, Ab_1An_1	55.6	28.3	5.7	10.4	2.679
Labradorite	Ab_1An_1, Ab_1An_3	49.3	32.6	2.8	15.3	2.708
Bytownite	Ab_1An_3, Ab_1An_6	46.6	34.4	1.6	17.4	2.742
Anorthite	$CaAl_2(SiO_4)_2$(An)	43.2	36.7	....	20.1	2.765

Nearly all plagioclases contain small traces of K_2O, MgO and Fe_2O_3, but otherwise their composition is nearly in accord with that demanded by their symbols, so that if one constituent is known the others may be calculated. Moreover, the accord between physical properties and composition is so close that from the former the latter may be determined.

Many oligoclases, however, contain a large admixture of the microcline molecule so that they contain a notable quantity of K_2O. These are known as *potash-oligoclase* and are represented by the feldspar in a rock at Tyveholmen, Norway, the composition of which is as follows:

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	H_2O	Total
59.50	22.69	2.47	5.05	tr.	2.50	6.38	1.37	100.37

Some authors limit the name *anorthoclase* to feldspars of this kind and designate the triclinic soda-potash feldspar as soda-microcline.

There is another group of soda-lime feldspars in which the anorthite molecule and an analogous sodic molecule ($Na_2Al_2(SiO_4)_2$) form isomorphous mixtures. The pure sodic molecule has not been found among minerals, but it has been prepared synthetically at temperatures above 1248°, under the name *carnegieite*. Its sp. gr. = 2.513 and its refractive indices for yellow light are: $\alpha = 1.509$, $\gamma = 1.514$. Although not known to exist independently it is believed to be present in the feldspar of Linosa, near Tunis, and possibly in other feldspars that have hitherto been described as plagioclases. If future work establishes the fact that there is a distinct series of feldspars composed of isomorphous mixtures of anorthite and carnegieite it is proposed to name the group *anemousite* to distinguish it from the plagioclase group which comprises isomorphous mixtures of anorthite and albite.

The Linosa feldspar has properties nearly like those of the plagioclase Ab_1An_1 but its analysis yields the results in line I. The composition of Ab_1An_1 is given in line II.

	SiO_2	Al_2O_3	CaO	Na_2O	K_2O	Sp. Gr.
I.	53.26	29.78	10.76	5.45	.75	2.684
II.	55.67	28.26	10.34	5.73	.00	2.679

THE PLAGIOCLASES

All the plagioclases have a triclinic habit, which is best expressed by the value of the angle between their cleavages, which are parallel to the planes 001 and 010. The crystal constants of some of the common mixtures and the values of their cleavage angles are given in the table below.

		α	β	γ	Angle 001 ∧ 010
Albite.....	$a : b : c = .6335 : 1 : .5577$	94° 3′	116° 29′	88° 9′	86° 24′
Oligoclase...	$= .6321 : 1 : .5524$	93° 4′	116° 23′	90° 5′	86° 32′
Andesine...	$= .6357 : 1 : .5521$	93° 23′	116° 29′	89° 59′	86° 14′
Labradorite.	$= .6377 : 1 : .5547$	93° 31′	116° 3′	89° 55′	86° 4′
Bytownite..					
Anorthite...	$= .6347 : 1 : .5501$	93° 13′	115° 55′	91° 12′	85° 50′

Crystals of the soda-rich plagioclases are rich in forms, but those of anorthite and the lime-rich members are much simpler. Albite crystals are usually tabular parallel to $\infty P \breve{\infty}$ (010) and elongated parallel to *c* or *a*. Others are elongated parallel to *b* (Fig. 221). Oligoclase is

more frequently columnar parallel to *c*, andesine tabular parallel to ∞P$\breve{\infty}$ (010) or oP(001), and labradorite and bytownite tabular parallel to ∞P$\breve{\infty}$ (010). Twins are even more common than among the potash feldspars. Carlsbad (Fig. 222), Manebach and Baveno twins are not uncommon, but more frequent than these are the twins after two laws that are impossible in the feldspars with a monoclinic habit. The two most common twinning laws among the plagioclases are the albite and the pericline laws.

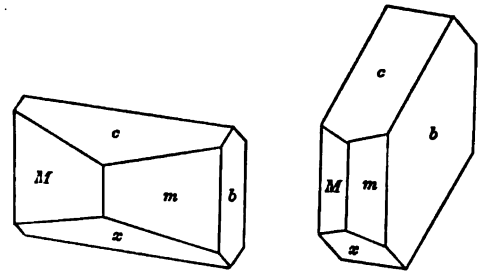


FIG. 221.—Albite Crystals with ∞'P, 1$\bar{1}$0 (*M*); ∞P', 110 (*m*); ∞P$\breve{\infty}$, 010 (*b*); oP, 001 (*c*) and ,P, $\bar{\infty}$, $\bar{1}$01 (*x*).

In the albite law the twinning plane is ∞P$\breve{\infty}$ (010) and the composition plane the same (Fig. 223). The twinning is usually repeated many times so that apparently homogeneous crystals may be built up of numerous lamellae parallel to 010. Since the angle between 010 and

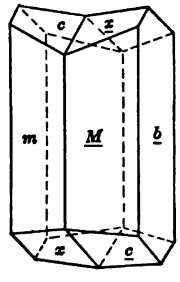


FIG. 222.

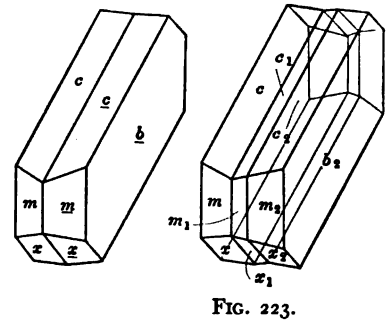


FIG. 223.

FIG. 222.—Albite Twinned about ∞P$\bar{\infty}$, 100. Composition face ∞P$\breve{\infty}$, 010. Carlsbad law. Compare Fig. 216.

FIG. 223.—Albite Twinned about ∞P$\breve{\infty}$, 010. Composition face the same. Albite law. Compare Fig. 222.

001 in all the plagioclases is greater and less than 90°, it must follow that the surface of their basal cleavages is not a plane, but that it consists of parallel strips of surfaces parallel to 010, and inclined to one another at angles alternately greater and less than 180°. Therefore basal cleavages

of the plagioclases very frequently exhibit parallel striations when examined in light reflected at the proper angles (Fig. 224). It is this twinning which, repeated in submicroscopic lamellae, is believed to produce the monoclinic pseudosymmetry of orthoclase. It will be noted that the twinning plane has the position of the plane of symmetry in monoclinic crystals, and, consequently, twins about this plane have the same symmetry with reference to one another as corresponding contiguous layers of monoclinic crystals.

FIG. 224.—Twinning Striations on Cleavage Piece of Oligoclase. (About natural size.)

In the pericline law the twinned portions are superposed. The individuals are twinned about *b* as the twinning axis, and are united about a plane nearly perpendicular to ∞ P ∞̆ (010), known as the "rhombic section" (Fig. 225). The position of this section varies with the different plagioclases, but is always nearly perpendicular to 010

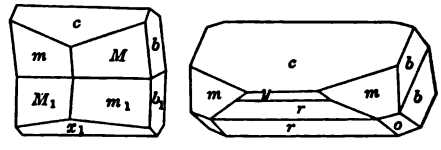


FIG. 225.—Albite Twins with the Crystal Axis *b* the Twinning Axis and the Rhombic Section the Composition Face. The form *r* is $\frac{4}{3}$P $\bar{\infty}$ ($\bar{4}$03). Pericline law.

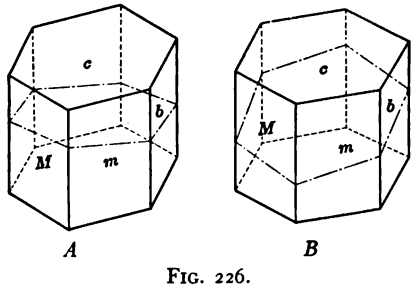


FIG. 226.

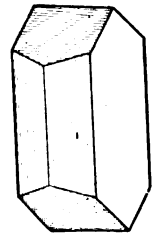


FIG. 227.

FIG. 226.—Position of "Rhombic Sections" in Albite (*A*) and Anorthite (*B*).
FIG. 227.—Diagram of Crystal of Triclinic Feldspar Exhibiting Striations Due to Polysynthetic Twinning According to the Albite and the Pericline Laws.

(Fig. 226). As nearly all pericline twins are elongated in the direction of the *b* axis, and the twinning is repeated, lamellae are produced,

which, in sections perpendicular to 010, cross the albite lamellae at angles near 90° (Fig. 227). It is the presence of the two kinds of twinning in microcline that gives it its peculiar grating structure in polarized light (see Fig. 219).

The plagioclases are light-colored, but pinkish and greenish shades are less common in them than in the potash feldspars. Their streak is colorless. They are usually translucent but in some cases are transparent. Albite often exhibits a pearly luster and often a bluish shimmer. Oligoclase when containing as little inclusions plates of hematite, glistens with a red shimmer and affords the finest sunstones. The most brilliantly colored plagioclases are some forms of labradorite, which, on cleavage surfaces, show a great display of yellow, green, red, purple and blue flashes in reflected light. The cause of the play of colors is not known, but it is probably due to the presence of numerous very tiny parallel acicular inclusions.

The refractive indices of the plagioclases vary with their compositions. For yellow light the values for the specified mixtures are as follows:

		α	β	γ
Albite	($Ab_{100}An_0$)	1.5290	1.5333	1.5386
Oligoclase	($Ab_{78}An_{22}$)	1.5389	1.5431	1.5469
Andesine	($Ab_{60}An_{40}$)	1.549	1.553	1.556
Labradorite	($Ab_{48}An_{52}$)	1.5545	1.5589	1.5634
Bytownite	($Ab_{20}An_{80}$)	1.5691	1.5760	1.5805
Anorthite	(Ab_9An_{91})	1.5752	1.5833	1.5884

Before the blowpipe all the plagioclases fuse to a white or colorless glass, at the same time coloring the flame an intense yellow (albite), or a yellowish red (anorthite). Albite fuses at a lower temperature than anorthite. The temperatures at which synthetically prepared plagioclases melt completely are as follows:

Anorthite	1,550°	Ab_2An_1	1,394°
Ab_1An_5	1,521	Ab_3An_1	1,362
An_1An_2	1,490	Ab_4An_1	1,334
Ab_1An_1	1,450	Ab_8An_1	1,265
Albite	1,100° est.		

Albite is unattacked by HCl, but anorthite is decomposed by this reagent with the separation of gelatinous or pulverulent silica. The intermediate plagioclases are more or less easily decomposed as they contain more or less of the anorthite molecule.

The plagioclases are distinguished from the feldspars possessing the

monoclinic habit by the twinning striations on their basal cleavages, and from the potash feldspars of both monoclinic and triclinic habits by the color imparted to the blowpipe flame. The characteristics of the plagioclases best distinguishing them from one another are their specific gravities and their optical properties.

The plagioclases weather to kaolin and mica (paragonite) mixed with quartz and calcite in the more basic varieties, and to zeolites (see p. 45). In rock masses the more basic varieties alter to epidote, in some instances into scapolite (p. 423), and very commonly into the mixture known as *saussurite*, which is an aggregate containing zoisite or garnet as its most important component.

Syntheses.—Crystals of plagioclase have been made by processes analogous to those employed in making orthoclase crystals. For example, albite crystals have been produced by fusing SiO_2 and Al_2O_3 with sodium wolframate, and by heating precipitated aluminium silicate with a solution of sodium silicate in a platinum tube to 500°. Anorthite crystals have been made by long heating of a mixture of SiO_2, Al_2O_3 and $CaCO_3$ in the proper proportions, and by fusing vesuvianite and garnet.

Occurrence.—Albite occurs in vein masses in certain crystalline schists but is much less common as a primary rock constituent than the other plagioclases. It is, however, frequently found as a secondary product resulting from the changes produced in other plagioclases by metamorphic processes, thus it is common in many crystalline schists. Oligoclase and andesine occur in granites and the other more siliceous igneous rocks and labradorite, bytownite and anorthite in the more basic rocks. Anorthite has also been found in meteorites.

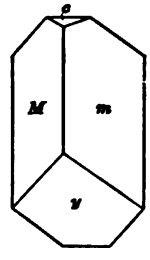


FIG. 228.—Potash-Oligoclase Crystal. Forms *M*, *m* and *c* as in Fig. 221. Also 2,P, $\bar{\infty}$, $\bar{2}01$ (*y*).

Localities.—The localities at which crystals of the plagioclases are found are too numerous to be mentioned here. Especially fine crystals of albite occur at Roc-Tourné in the French Alps, in Dauphiné, France; at Amelia Court House, Va.; at Middletown, Conn.; and at Chesterfield in Massachusetts. Excellent crystals of oligoclase occur at Arendal and at other places in Norway; and at McComb and Fine, in St. Lawrence Co., N. Y. Potash-oligoclase occurs in certain igneous rocks at Tyveholmen and elsewhere in Norway and in the lava of Kilimandjaro, Africa. Its habit is prismatic (Fig. 228). Crystals of andesine are found at Bodenmais, in Bavaria; Arcuentu, in Sardinia; and at Sanford,

in Maine. Labradorite crystals occur at Visegrad, Hungary; and at Mt. Aetna, Italy; and beautiful cleavage pieces come from Labrador, where it forms one of the constituents of a coarse-grained igneous rock. Anorthite crystals occur at Volpersdorf, in Silesia; in the Aranya Mt., Siebenburgen, Hungary; at Pesmeda, Tyrol; in the inclusions in the lavas at Vesuvius, Italy; in the lava on the Island of Unjake, Japan; and at Phippsburg, in Maine.

Uses.—Albite from the pegmatite veins of southeastern Pennsylvania and northeastern Maryland is mined for use in pottery manufacture.

SCAPOLITE GROUP

$(Na_4Al_2(AlCl)(Si_3O_8)_3 + Ca_4Al_5(AlO)(SiO_4)_6)$

The scapolites comprise a series of isomorphous compounds of which the two end members are ***marialite***, $Na_4Al_2(AlCl)(Si_3O_8)_3$ and ***meionite***, $Ca_4Al_5(AlO)(SiO_4)_6$. Between these two are many intermediate compounds known under the collective name ***mizzonite***. Their composition is represented in terms of the marialite and meionite molecules, thus, Ma_mMe_n.

The theoretical compositions of the two end members of the series and of several intermediate members, and the actual compositions of four specimens of natural crystals are given below.

	SiO_2	Al_2O_3	CaO	Na_2O	Cl	Total
Theoretical, Ma.....	63.95	18.12	.....	14.69	4.19	100.95
Theoretical, Ma_3Me..	57.85	22.35	6.53	10.87	3.10	100.70
Theoretical, Ma_2Me..	55.85	23.73	8.67	9.62	2.75	100.62
Theoretical, MaMe ..	51.90	26.47	12.90	7.15	2.04	100.46
Theoretical, $MaMe_2$..	48.03	29.16	17.04	4.76	1.35	100.34
Theoretical, $MaMe_3$..	46.10	30.48	19.10	3.54	1.01	100.23
Theoretical, Me.....	40.45	34.38	25.17	....	....	100.00

	SiO_2	Al_2O_3	CaO	Na_2O	K_2O	H_2O	Cl	Total
I.	61.40	19.63	4.10	?	?	....	4.00	
II.	54.86	22.45	9.09	8.36	1.13	.86	2.41	100.45
III.	49.40	30.02	15.62	3.11	.79	.64	.13	100.03
IV.	41.80	30.40	19.00	2.51	.86	3.17*	....	98.66

I. Marialite, Pianura, Italy.

II. Riponite, Ripon, Quebec. Contains also .80% SO_3, .49 Fe_2O_3 and a trace of MgO.

III. Wernerite, Rossie, N. Y. Contains also .10% SO_3 and .32 FeO.

IV. Meionite, Mt. Vesuvius. Contains also .46 MgO and .46% undecomposed material.

*Volatile.

All the members crystallize in the pyramidal hemihedral division of the tetragonal system (tetragonal bipyramidal class) in fairly simple columnar crystals with an axial ratio 1 : .442 for marialite and 1 : .4393 for meionite. The principal forms are oP(001), ∞P∞ (100), ∞P(110), ∞P2(210), P(111), P∞ (101) and $\left[\frac{3P3}{2}\right]$(311) (Fig. 229). The angle $111 \wedge 1\bar{1}1 = 43° 45'$. The habit of the crystals is always columnar, with ∞P∞ (100) predominating in the prismatic zone, and also ∞P(110) prominent. The latter form predominates only in mizzonites. The scapolites occur also in crystal grains embedded in limestones, in columnar and fibrous aggregates and in structureless masses.

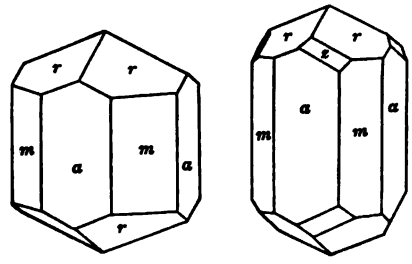


FIG. 229. — Scapolite Crystals with ∞P, 110 (*m*); ∞P∞, 100 (*a*); P, 111 (*r*), and $\left[\frac{3P3}{2}\right]$, 311 (*z*).

All the scapolites have a glassy luster, which approaches pearly. They are transparent or translucent, colorless or white, gray, greenish, bluish or reddish and have a white streak. Their cleavage is nearly perfect parallel to ∞P∞ (100) and imperfect parallel to ∞P(110). Their fracture is uneven or conchoidal. They are brittle, have a hardness of 5–6 and a density of 2.54 for marialite and 2.76 for meionite. The refractive indices naturally vary with the proportions of the two molecules present. For the two end members of the group the indices for yellow light are: marialite, $\omega = 1.5463$, $\epsilon = 1.5395$, meionite, $\omega = 1.5897$, $\epsilon = 1.5564$.

Before the blowpipe all members swell and fuse to a white glass. In hydrochloric acid, mixtures between Ma and Ma_2Me are insoluble, those between Ma_2Me and $MaMe_2$ are partially soluble and those between $MaMe_2$ and Me are nearly completely soluble.

All members of the series are distinguished by their crystallization and cleavage and all except pure meionite are characterized by the chlorine reaction. They are distinguished readily from the feldspars by their fusibility with swelling.

Marialite and meionite are rare. The common scapolites are the mizzonites of which *dipyr* and *wernerite* are the nontransparent varieties. The former includes varieties occurring in elongated prisms containing between 54 per cent and 57 per cent SiO_2, i.e., Ma_3Me to Ma_2Me,

and the latter embraces varieties containing between 54 per cent and 46 per cent SiO_2, or Ma_2Me to $MaMe_3$.

Occurrence.—The scapolites occur in crystalline schists, crystalline limestones and also in limestones included in volcanic lavas (meionite), and on the contacts of igneous masses (wernerite). They are found also in igneous rocks as the result of alteration of the feldspars, especially when these rocks are intrusive in limestones, and also as an alteration product of garnets. In a few places they are associated with magnetite and apatite in veins of iron ores. In most cases they appear to have been derived from feldspars by the action of metamorphic processes. On the other hand, scapolite changes to albite, epidote, biotite, muscovite and to a mixture of minerals.

Localities.—Meionite crystals occur in the fragments enclosed in the lavas of the Lake Laach region, Prussia; and of Monte Somma, the precursor of Vesuvius, Italy. Mizzonite is associated with meionite at Monte Somma. Dipyr occurs in clayey limestones in the Pyrennees; wernerite at Arendal and Bamle, Norway; at Malsjö, in Sweden; at Diana, Lewis Co., and at Gouverneur and Pierrepont, St. Lawrence Co., N. Y.; at Canaan, Conn.; at Bolton, Mass.; and marialite at Ripon, Quebec, and at Pianura, near Naples, Italy.

CHAPTER XIX

THE SILICATES—*Continued*

THE ANHYDROUS POLYSILICATES

UNDER the polysilicates are grouped all the minerals that cannot easily be assigned to the orthosilicates, the metasilicates or the trimetasilicates. They are usually very complex in composition and are commonly regarded as isomorphous mixtures or solid solutions of silicate molecules of various types.

THE BRITTLE MICAS

The brittle micas are so called because, while they possess a very marked cleavage which rivals that of the true micas in its perfection, their cleavage foliae are brittle, and not elastic as are the mica foliae.

The group consists of four minerals of which three are apparently mixtures of the molecules $H_2CaMg_4(SiO_4)_3$ and $H_2CaMgAl_6O_{12}$, and the fourth is approximately $H_2(Fe \cdot Mg)Al_2SiO_7$. The first three are known as *xanthophyllite*, *brandisite* and *clintonite* and the fourth as *chloritoid*. Of these the last two are the most important. Chloritoid is believed to be a basic orthosilicate, but, because of the similarity of its properties to those of the brittle micas, it is thought best to discuss it in the same group with them.

All members of the group crystallize in the monoclinic system with an hexagonal habit.

Clintonite ($H_6(Mg \cdot Ca \cdot Fe)_{10}Al_{10}Si_4O_{36}$)

Clintonite, or seybertite, may be regarded as a mixture of the molecules $H_2CaMg_4(SiO_4)_3$ and $H_2CaMgAl_6O_{12}$ in the proportion 4 : 5, which requires the percentage composition shown in line I below. The analysis of a specimen of the mineral from Orange Co., N. Y., is given in line II:

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	H_2O	F	Total
I.	19.09	40.97	...	....	22.28	13.36	4.30	....	100.00
II.	19.19	39.73	.61	1.88	21.09	13.11	4.85	1.26	101.72

Well developed crystals are so rare that their axial ratio has not been satisfactorily established. The best crystals appear as long, thick, six-sided plates with a well developed basal plane and several pyramids and domes with rounded edges. If the axial ratio is assumed to be the same as that for biotite the principal forms are oP(001), $\frac{8}{7}$P $\breve{\infty}$ (027), $\frac{5}{6}$P $\breve{\infty}$ (056), $\frac{5}{2}$P $\breve{\infty}$ (052), $-\frac{1}{4}$P(114), $-\frac{3}{7}$P(337), and -2P(221). Many of the crystals are superposed twins, like those of muscovite. (Fig. 230.)

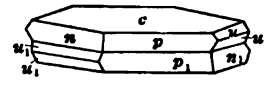


FIG. 230.—Clintonite Twinned According to the Mica Law. Forms: oP, 001 (*c*); $-\frac{3}{7}$P, 337 (*p*) and $\frac{1}{2}$P $\breve{\infty}$, 012 (*u*).

The mineral is reddish or brown, and transparent or translucent. It has a glassy luster and a white streak. Pressure and percussion figures are easily produced on the cleavage plates, and in nature parting often takes place along these directions, yielding fragments with rectangular edges. The hardness of clintonite is 4–5 and its density 3.1. Its refractive indices for yellow light are: $\alpha = 1.646$, $\beta = 1.657$, $\gamma = 1.658$.

Before the blowpipe clintonite becomes white and opaque but does not fuse. In the closed tube it gives off water. It is completely decomposed by hydrochloric acid.

It is distinguished from most other minerals by its micaceous cleavage, and from the true *micas* by its brittleness and solubility in hydrochloric acid.

Clintonite occurs in a coarse, serpentinized limestone at Amity, Orange Co., N. Y.

Chloritoid ($H_2(Fe \cdot Mg)Al_2SiO_7$)

Chloritoid differs from the other brittle micas in being essentially a ferrous compound. Its composition approaches the formula given above, though the analyses of many specimens depart widely from this.

	SiO_2	Al_2O_3	FeO	MgO	H_2O	Total
I.	23.72	40.71	28.46	....	7.11	100.00
II.	25.50	38.13	23.58	5.19	6.90	99.30

I. Theoretical for $H_2FeAl_2SiO_7$.
II. Specimen from chlorite schists, St. Marcel, Italy.

The mineral is believed to be monoclinic in crystallization because of the similarity of its crystals to those of biotite. It often occurs in six-sided plates, but more frequently in lenticular or spindle-shaped grains and sheaf-like and ball-like aggregates of plates and grains and in foliated masses. Twins like those of biotite are also fairly common.

The mineral is dark green or black, and translucent. It is strongly pleochroic in olive green, blue and yellowish green tints. It has a glassy or pearly luster on its cleavage faces and a waxy luster on fracture surfaces. Its hardness is 6–7 and density 3.4–3.6. Its refractive index is 1.741.

Before the blowpipe chloritoid exfoliates on the edges and fuses with difficulty to a black magnetic mass. In the closed tube it gives off water. It is unattacked by hydrochloric acid, but when in fine powder is completely decomposed by sulphuric acid. Some forms of ottrelite are soluble in strong nitric and hydrochloric acids, with the separation of gelatinous silica.

Masonite is a dark grayish variety from Natick, R. I.

Ottrelite contains a little manganese and has a slightly different formula from chloritoid. Its composition may be best represented by $H_2(Fe \cdot Mn)Al_2Si_2O_9$. Its sp. gr. = 3.3.

The chloritoids appear to be fairly stable, as their only alteration products thus far noted are the chlorites and the micas and ottrelite.

Occurrence.—All varieties of chloritoid are found principally in fine-grained schists where they are believed to be the result of regional and contact metamorphism.

Localities.—The most noted occurrences of chloritoid are Pregattan, Tyrol; St. Marcel, Italy; Ottrez, Belgium; Natick, R. I., and Augusta and Patrick Counties, Va.

CHLORITE GROUP

The chlorite group is so named because its principal members are green. The group comprises a number of platy hydrous magnesium, aluminium silicates that appear to be isomorphous mixtures of molecules that are approximately $H_4(Mg \cdot Fe)_2Al_2SiO_9$ and $H_4(Mg \cdot Fe)_3Si_2O_9$, the former of which is known as the *amesite* molecule (designated At), and the latter as the *serpentine* molecule (indicated by Sp). The serpentine molecule is represented in the platy form of serpentine known as *antigorite*, which may be regarded as one of the end members of the series. The independent existence of the amesite molecule is doubtful. The mixture of these two molecules gives rise to the *orthochlorites*, which constitute the principal of the two subgroups of the chlorites. The other subgroup is known as the group of the *leptochlorites*. These consist of one or both of the two molecules mentioned above and others that may be regarded as derived from them. Their composition is too complex to be represented by any simple formula.

ORTHOCHLORITES

The orthochlorites comprise the minerals:

			SiO_2	Al_2O_3	FeO	MgO	H_2O
Corundophilite.	$SpAt_4 - Sp_3At_7$	$SpAt_4$ =	26.1	29.3	....	31.8	12.8
Prochlorite....	$Sp_3At_7 - Sp_2At_3$	$SpAt_2$ =	25.5	21.6	26.6	14.9	11.4
Clinochlore....	$Sp_2At_3 - SpAt$	Sp_2At_3 =	30.03	22.0	....	34.8	12.9
Penninite.....	$SpAt - Sp_3At_2$	Sp_3At_2 =	34.7	14.6	....	37.7	13.0

Analyses of typical specimens are as follows:

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	H_2O	Total
I. Corundophilite	24.77	25.52	....	15.19	21.88	...	11.98	99.34
II. Prochlorite....	26.02	20.16	1.07	28.08	15.50	.44	9.65	100.92
III. Clinochlore...	29.87	14.48	5.52	1.93	33.06	...	13.60	100.19*
IV. Penninite.....	33.71	12.55	2.74	3.40	34.70	.66	12.27	100.03

I. Chester, Mass.
II. Zillerthal, Tyrol.
III. West Chester, Pa.
IV. Zermatt, Switzerland.

* Contains also NiO = .17, Cr_2O_3 = 1.56.

The orthochlorites crystallize in tabular and pyramidal crystals that are usually repeated twins so that their true nature is difficult to decipher. The simpler crystals have a monoclinic habit, but the twins are usually hexagonal or rhombohedral in habit. Their crystallization is believed to be monoclinic, with the axial ratio .5774 : 1 : 2.2772 and $\beta = 89° 40'$. The most common forms appearing on them are oP(001), $P\breve{\infty}$ (011), $\frac{2}{5}P(\bar{2}25)$, $\frac{1}{2}P(\bar{1}12)$, $\frac{4}{3}P\breve{\infty}$ (043), $-\frac{4}{11}P\bar{\infty}$ (4.0.11), $\infty P\bar{\infty}$ (101) and $-6P\bar{3}(261)$ (Fig. 231). Twins are very common. The two most common twinning laws are the mica and the pennine laws. In the former the twinning plane is perpendicular to oP(001) and in the zone with oP(001) and $-\frac{1}{2}P(112)$ (Fig. 232, compare Fig. 193). The two parts are revolved 60° with respect to one another. In the pennine law oP(001) is the twinning plane and the composition face (Fig. 233). Twins following the first law have their twinned parts either side by side (Fig. 234), or superposed (Fig. 232). Those following the pennine law have their parts superposed. The twinning is often repeated so that complicated trillings and sixlings are produced.

Clinochlore crystals are tabular with hexagonal outlines but a monoclinic habit (Fig. 231), and penninite is in thick tabular crystals with a

trigonal outline and a rhombohedral habit, or in slender prismatic ones resembling steep rhombohedrons (Fig. 235). Its characteristic twins are according to the pennine law. (Fig. 236). Prochlorite and corundophilite are found in six-sided plates without well developed crystal forms.

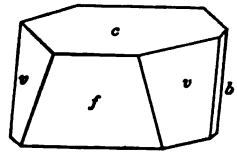


FIG. 231.

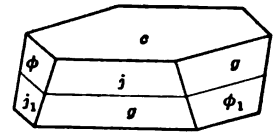


FIG. 232.

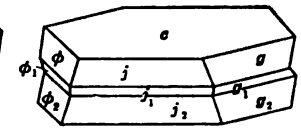


FIG. 233.

FIG. 231.—Clinochlore Crystal with oP, 001 (*c*); $\infty P\bar{\infty}$, 010 (*b*); $4P\bar{\infty}$, $\bar{4}01$ (*f*), and $-\frac{3}{2}P\bar{3}$, 132 (*v*).

FIG. 232.—Clinochlore Twinned According to Mica Law, in which the Twinning Plane is Perpendicular to oP(001) and in the Zone with oP(001) and $-\frac{1}{2}P(112)$. Forms: oP, 001 (*c*); $\frac{11}{30}P\bar{\infty}$, $\bar{3}\bar{1}.0.30$ (*j*); $-6P\bar{3}$, 261 (*g*) and $\frac{27}{17}P\bar{3}$, $9.\overline{27}.17$ (*φ*).

FIG. 233.—Clinochlore with Same Forms as in Fig. 232. Twinned about oP(001) as Twinning and Composition Face. Pennine law.

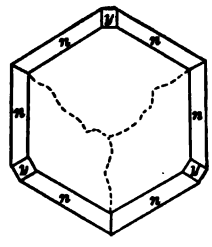


FIG. 234.

FIG. 235.

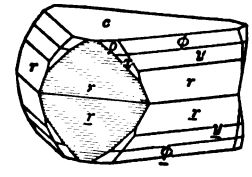


FIG. 236.

FIG. 234.—Clinochlore Trilling Twinned According to Mica Law, but with Individuals Side by Side with oP(001) common and Irregular Composition Faces. $n = \frac{2}{3}P$, $(\bar{2}25)$ and $y = \frac{2}{5}P\bar{\infty}$ $(\bar{2}05)$.

FIG. 235.—Penninite Crystal with oP, 001 (*c*) and a Form Resembling 3R, $30\bar{3}1$ (*w*).

FIG. 236.—Penninite Crystal Twinned about oP(001). Pennine Law.

The orthochlorites have a glassy luster with a slightly pearly luster on the basal plane. They are usually some shade of green, blackish and bluish green being the most common shades. At a few localities white or yellow varieties are found. Varieties containing chromium are often

rose-colored or violet. The streak of all varieties is white or light green. All are strongly pleochroic in shades of green in green varieties, yellow and brown in brown varieties, and violet and carmine in rose varieties. Their cleavage is distinct parallel to the base (001), yielding lamellae that are flexible and slightly elastic. Percussion and pressure figures, with rays in the same relative positions as in the micas, occur naturally and often a parting takes place along their planes yielding triangular plates. The hardness of all orthochlorites is below 3 and their density is 2.5–3. For the different varieties these properties are:

	H	Sp. Gr.
Prochlorite.....	1–2	2.78–2.96
Clinochlore.....	2–2.5	2.65–2.78
Penninite.....	2–2.5	2.6 –2.85
Corundophilite.....	2.5	2.9

The refractive indices for yellow light are: in penninite, $\beta=1.575$, in clinochlore, $\alpha=1.585$, $\beta=1.585$, $\gamma=1.596$, in prochlorite, $\beta=1.58+$ and in corundophilite, $\beta=1.583$.

Before the blowpipe the orthochlorites exfoliate and fuse with difficulty. Some varieties whiten. The varieties rich in iron fuse more readily than those in which there is little iron—in some instances to a black glass. In the closed tube all yield water when strongly heated. Hydrochloric acid attacks all varieties with difficulty—after fusion with more ease. Sulphuric acid completely decomposes them.

Synthesis.—Chlorites have been produced artificially by the action of alkaline solutions on pyroxenes.

Occurrences.—The orthochlorites are alteration products of various silicates. They occur as essential constituents in crystalline schists (chlorite schists), and as the alteration products of silicates in igneous rocks, in which case the latter assume a green color. The orthochlorites also form pseudomorphs after garnet, biotite, augite, hornblende, etc., and sometimes they occur filling little veins cutting through altered rocks. Corundophilite is frequently associated with the mineral corundum.

Localities.—The localities at which the orthochlorites occur are so numerous that even all of the most important cannot be mentioned here. In the United States corundophilite occurs at Chester, Mass., and Asheville, N. C.; pyrochlorite at Foundryrun, Georgetown, D. C., and at Batesville, Va.; penninite at Magnet Cove, Arkansas; and clinochlore at West Chester, Penn.

LEPTOCHLORITES

The name leptochlorite is usually given to the chlorites that occur in fine scales and fibers. They are very complex in composition. Because they do not occur in distinct crystals their crystallization is not certainly known.

The leptochlorites are like the orthochlorites in general appearance, and in origin. They are, however, completely soluble in hydrochloric acid with the separation of gelatinous silica.

Of this group *thuringite* and *delessite* are the best known. The former is in very fine dark green and pleochroic scales. It fuses to a black magnetic bead. It forms pseudomorphs after garnet at the Spurr Mt. iron mine, at Spurr, Mich. Delessite is usually green, but is in rare cases pink. It usually occurs in bundles of fibers that are strongly pleochroic. The green varieties, viewed across the fibers are dark green. Viewed along their axes they are yellow. This chlorite is a common alteration product of pyroxene and amphiboles, and it frequently occurs as the filling of amygdules in basic volcanic rocks. The mineral when heated becomes brown or black and finally fuses with difficulty to a black magnetic bead.

Analyses of typical specimens of the two minerals are given in the following table:

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	H_2O	Total
Thuringite, Spurr, Mich.	22.35	25.14	....	34.39	....	6.41	11.25	99.54
Delessite, Dumbarton, Scotland	32.00	17.33	1.19	12.45	1.57	20.42	15.45	100.41

Vesuvianite

Vesuvianite is a common metamorphic mineral in limestones. It is extremely complex in composition, apparently consisting of isomorphous mixtures of the two compounds $Ca_6Al_2Al(OH \cdot F)(SiO_4)_5$ and $Ca_2Al(OH)Si_2O_7$. Its composition may perhaps be better represented by the general formula $R'_4Al_2Ca_7Si_6O_{24}$, in which R'_4 may be $Ca_2,(AlOH)_2$, $(AlO_2H)_4$ or H_4. Four analyses, which emphasize the great variations in composition shown by crystals from different localities are quoted below:

	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	MnO	K_2O
I.	36.08	9.35	7.61	....	29.09	1.90	12.49	.28
II.	37.11	19.30	3.31	....	36.24	3.89	.....	...
III.	36.41	17.35	1.86		33.21	1.38	1.75	.50
IV.	36.55	18.89	.74	.74	35.97	2.33	.....	...

	Na_2O	F	H_2O at 100°	H_2O+		Less O=F	Total
I.	.55	...	...	3.32	100.67		
II.	...	.58	...	.06	100.49	.24	100.25
III.	.44	.36	.24	3.51	100.23	.15	100.08
IV.	...	.13	.58	3.42	100.26	.05	100.21

I. Garnet colored masses and crystals form Pajsberg, Sweden.
II. Finely crystallized material from Italian Mt., Gunnison Co., Colo.
III. From Franklin Furnace, New Jersey. Contains also ZnO=1.74, CuO=1.48, and a trace of PbO.
IV. Californite. Fresno Co., Cal. Also .91 per cent CO_2.

Vesuvianite occurs both massive and crystallized. Its crystals are in the tetragonal system (ditetragonal bipyramidal class), with an axial ratio of about 1 : .5375. This varies with the composition and is, therefore, different in specimens from different localities. The crystals are usually thick columnar in habit, but some crystals are pyramidal and others acicular. The columnar crystals usually contain ∞P(110) and ∞P∞ (100) in the prismatic zone, and oP(001), P(111), and often P∞(101), 3P(331), ∞P2(210), and 3P3(311) (Fig. 237). In all about 60 forms have been observed on them. The angle 111∧1$\bar{1}$1 = 50° 39′.

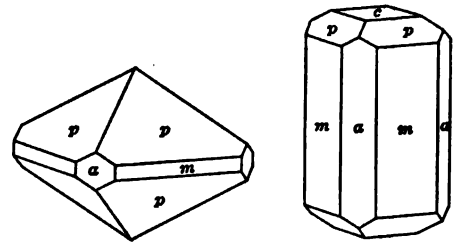


FIG. 237.—Vesuvianite Crystals with ∞P, 110 (*m*); ∞P∞, 100 (*a*); P, 111 (*p*) and oP, 001 (*c*).

The mineral is glassy in luster and yellowish, greenish or brownish, rarely blue or pink. It is transparent or translucent. A bright green, or gray and green, translucent, massive variety from points in California is used as a gem under the name *californite*. The streak of all varieties is white. The cleavage of the mineral is indistinct parallel to ∞P(110) and ∞P∞ (100) and its fracture conchoidal. Its hardness is 6–7 and density 3.35–3.45. Its refractive indices for yellow light are: ω=1.705, ϵ=1.701.

Before the blowpipe vesuvianite melts to a swollen brown or green glass. It is decomposed with difficulty by acids, but after being strongly heated it dissolves with the separation of gelatinous silica. The mineral powder reacts alkaline.

The mineral is characterized by its form when in crystals and by its easy fusibility.

The recognized varieties that are used as gems are:

Californite, a white, green or gray and green variety in finely granular masses, resembling jade.

Cyprine, a blue variety containing copper.

Its principal alteration products are mica, chlorite and steatite; and other minerals are also known to be formed from it by weathering.

Occurrence.—Vesuvianite is preëminently a contact mineral. It occurs in limestone metamorphosed by granite and other igneous rocks, and also in crystalline schists. It is found also as well developed crystals on the walls of veins containing quartz, calcite, garnet and ore minerals.

Localities.—Good crystals are common at a number of places where limestones are in contact with igneous rocks, notably at Pfitsch, and in the Monzoni Mts., in Tyrol; at Zermatt and at other points in Switzerland; at Vesuvius, in the Alathal, and the Albanian Mts., in Italy; and at many places in Norway and Sweden. In North America good crystals occur at Sandford, Phippsburg and other places in western Maine; near Amity, N. Y., and at Templeton, Quebec, and a fine-grained, massive variety occurs in Inyo and Tulare Counties, in California. Californite is best known from Indian Creek, Siskiyou Co., and from a point 35 miles east of Selma, in Fresno Co., California. Other localities are at Big Bar Station, Butte Co., and Exeter, in Tulare Co., in the same State.

Production.—The quantity of californite used as a gem stone in 1909 was about 3,000 lb., valued at $18,000. In 1912, however, only $275 worth was used.

Tourmaline ($R_9Al_3(B \cdot OH \cdot F)_2Si_4O_{19}$)
R = H, Al, Mg, Fe, Al, Cr, Fe, K, Na

Tourmaline is of great scientific interest because of its complex crystallization, its handsome crystals and the physical properties which it exhibits so beautifully. Moreover, it furnishes gems of many colors, which, because of their brilliancy, are greatly admired by many persons. The mineral appears to be a derivative of the alumino-borosilicic acid

$H_9Al_3(B \cdot OH)_2Si_4O_{19}$ in which the hydrogen may be replaced by Al, by Cr, by Mg and Fe″ or by Li or Na, giving rise to four groups of compounds between which are many gradations. Moreover, in most specimens a portion of the hydroxyl is replaced by fluorine. In other words, the mineral is an isomorphous mixture of several substances that are derivatives of the alumino-borosilicic acid mentioned. The four groups of tourmalines that are clearly distinguishable are:

1. *Alkali tourmalines*, which are colorless, red or green, and transparent.

2. *Iron tourmalines*, which are usually dark blue or black and translucent.

3. *Magnesium tourmalines*, which are yellowish brown, or brownish and translucent.

4. *Chrome tourmalines*, which are dark green, black and translucent, or colorless and transparent.

Typical analyses of these four varieties follow:

	I	II	III	IV
SiO_2	38.07	34.99	37.39	36.56
B_2O_3	9.99	9.63	10.73	8.90
Al_2O_3	42.24	33.96	27.89	32.58
Cr_2O_3	.....	.....	.....	4.32
FeO	.26	14.23	.64	....
MnO	.35	.06	.....	tr.
CaO	.56	.15	2.78	.75
MgO	.07	1.01	14.09	9.47
Na_2O	2.18	2.01	1.72	2.22
K_2O	.44	.34	.16	.13
Li_2O	1.59	tr.	tr.	tr.
H_2O	4.26	3.62	3.83	3.74
F	.28	.....	tr.	.06
TiO_2	.....	.....	1.19	.09
Total	100.29	100.00	100.42	99.70

I. Rose-colored (rubellite), from Rumford, Maine.
II. Black, from Auburn, Maine.
III. Brown, from Gouverneur, N Y. The Al_2O_3 includes .10 of Fe_2O_3.
IV. Green, from Etchison, Montgomery Co., Md. Contains also .79 Fe_2O_3, .05 NiO and .04 P_2O_5.

The varieties recognized by distinct names are (1) *ordinary*, black and brown, (2) *rubellite*, pink or red, (3) *indicolite*, blue or bluish black, (4)

Brazilian sapphire, blue and transparent, (5) *Brazilian emerald*, or *Brazilian chrysolite*, green and transparent, (6) *peridot* of Ceylon, honey-yellow and transparent and (7) *achroite*, colorless and transparent.

Tourmaline forms handsome crystals that are frequently characterized by possessing a triangular cross-section. They crystallize in the rhombohedral division of the hexagonal system and are hemimorphic (ditrigonal pyramidal class), with an axial ratio of 1 : .4474. The crystals are usually prismatic or columnar in habit, and are terminated by

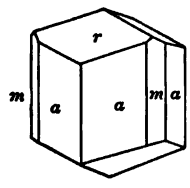
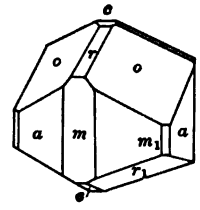


FIG. 238.



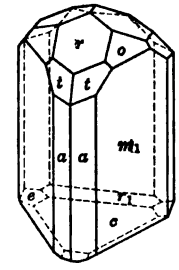


FIG. 239.

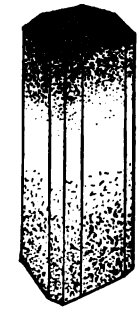


FIG. 240.

FIG. 238.—Tourmaline Crystals with $+\frac{\infty P}{2}$, $10\bar{1}0$ (m); $-\frac{\infty P}{2}$, $01\bar{1}0$ (m_1); $\infty P2$, $11\bar{2}0$ (a), and $+\frac{P}{4}u$, $10\bar{1}1$ (r); $-\frac{2P}{4}u$, $02\bar{2}1$ (o) and oP, 001 (c) at analogue pole, and $+\frac{P}{4}l$, $01\bar{1}\bar{1}$ (r_1) and $-\frac{\frac{1}{2}P}{4}l$, $01\bar{1}2$ (e) at antilogue pole.

FIG. 239.—Tourmaline Crystal with a, m, m_1, c, o, r, r_1 and e as in Fig. 238. Also $+\frac{3P\frac{3}{2}}{4}u$, 2131 ($t$). c is at antilogue pole.

FIG. 240.—Cooling Crystal of Tourmaline Powdered with a Mixture of Minium and Sulphur to Show the Distribution of the Electric Charge. The upper end is the analogue pole.

rhombohedrons. The most prominent prismatic faces are $\infty P(10\bar{1}0)$, $\infty P2(11\bar{2}0)$ and the most common terminal faces $R(10\bar{1}1)$, $-\frac{1}{2}R(01\bar{1}2)$, $-2R(02\bar{2}1)$, $R^3(21\bar{3}1)$, $R^5(32\bar{5}1)$ and $-\frac{1}{2}R^3(12\bar{3}2)$, though many other rhombohedrons and scalenohedrons have been observed. Most forms are hemimorphs so that the opposite ends of the c axis are differently terminated (Figs. 238 and 239). The prismatic faces are vertically striated and the interfacial edges are often rounded. The angle $10\bar{1}1 \wedge \bar{1}101 = 46° 52'$.

The mineral has a vitreous luster whether transparent or opaque. It

is brittle and has no distinct cleavage. Its fracture is conchoidal. Its hardness is 7–7.5 and its density: 3.007–3.134 for alkali varieties; 3.036–3.104 for magnesian varieties; 3.140–3.212 for blue iron varieties and 3.122–3.220 for green and black varieties. The color varies more than in any other mineral, the same crystals often exhibiting different colors at opposite terminations. Moreover, many crystals show a zonal arrangement of colors, with concentric colorless, red and green layers. The streak of all varieties is uncolored. The mineral becomes electrified by friction and like other hemimorphic substances is pyroelectric. The analogue pole is usually more simply terminated than the antilogue pole, in many instances showing only R($10\bar{1}1$) (Fig. 240). The refractive indices for yellow light in colorless crystals are: $\omega = 1.6422$, $\epsilon = 1.6225$. In iron-bearing varieties the refraction is stronger.

Dark varieties exhibit very strong pleochroism. Viewed in the direction of the *c* axis the mineral is always, except in the case of colorless varieties, darker than when viewed in a direction at right angles to it. In very dark varieties the ray vibrating perpendicular to *c* is almost completely absorbed, while the ray vibrating parallel to *c* passes through with a dark brown or dark green tint. Thus, thin slices cut parallel to the *c* axis will let through only light that vibrates in the plane parallel to *c*. Tourmaline tongs are two such pieces or plates of dark tourmaline mounted so that they may be revolved in their own planes. When the *c* axes in the two plates are parallel light is transmitted. This light is said to be polarized because it all vibrates in a single plane. When the *c* axes are crossed the light that passes through the first plate is entirely absorbed by the second, so that no light passes through.

The behavior of tourmaline before the blowpipe varies widely. Alkaline varieties are practically infusible. Iron varieties fuse with great difficulty and magnesium varieties very easily to a blebby glass.

When fused with a mixture of acid potassium sulphate and powdered fluorspar all varieties give a distinct reaction for boric acid.

Tourmaline is readily distinguished from all other minerals by its crystallization, hardness, lack of cleavage and the reaction for boron. In massive forms it differs from *garnet* and *vesuvianite* which it somewhat resembles by its difficult fusibility and brittleness. The mineral is, on the whole, very stable. It is known, however, to alter into mica, chlorite and steatite.

Synthesis.—The mineral has not been produced artificially.

Occurrence.—Tourmaline is a characteristic pneumatolitic product. It occurs in pegmatites, in quartz and ore veins, and in limestones and schists on the peripheries of granite masses where it is the result of

contact action. It occurs also as an original, pyrogenic mineral in acid igneous rocks. The variety in limestone is usually brown. The lithium varieties are usually associated with lepidolite.

Uses.—The transparent varieties are used principally as gem stones, and the darker, translucent varieties in optical instruments.

Localities.—Tourmaline is so common that an enumeration of its occurrence is impossible in the present place. Red or green transparent varieties occur at Ekaterinburg, Ural; on the Isle of Elba; at Campolonga, Switzerland; Penig, Saxony, and in Minas Geraes, Brazil. In the United States fine brown crystals occur in the limestone at Gouverneur, N. Y.; and handsome black ones at Pierrepont, N. Y.; New Hope, Penn.; and in Alexander Co., N. C. The gem tourmaline occurs at several points in western and central Maine; at Haddam, Conn.; and in San Diego Co., in California. The Maine localities are at Hebron, Paris, Poland and Auburn. The tourmalines are in pockets in pegmatite. The green varieties are most common, but all colors occur, and many crystals are variegated. The centers of the gem industry in California are Pala and Mesa Grande, San Diego Co., where many pink tourmalines and a few green crystals occur associated with the lithium mica, lepidolite, in pockets in a pegmatite dike. The best of these when cut bring $20 per carat.

Production.—The total output of gem tourmaline in the United States during 1909 was 5,110 pounds, valued at $133,192, but in 1912 the yield had fallen to $28,200.

Cordierite ($(Mg \cdot Fe)_2Al_2(AlO)_2Si_5O_{16}$)

Cordierite, dichroite, or iolite, may be an isomorphous mixture of several molecules. Its composition is apparently as shown by the formula given above, although the persistent appearance of water in all recent analyses may indicate the presence of hydroxyl in the molecule. Since, however, the mineral readily undergoes weathering, most authors regard the water as due to some hydrous alteration product. If the water is regarded as essential the formula becomes $H_2(Mg \cdot Fe)_4Al_8Si_{10}O_{37}$. The calculated composition of the mineral and the actual compositions of some specimens, as shown by analyses, are:

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	H_2O	Total
Theoretical....	51.36	34.96	....	....	...	13.68	....	100.00
Haddam, Conn.	49.14	32.84	.63	5.04	.19	10.40	1.84	100.08
Cabo de Gata..	48.58	32.44	3.15	9.17	tr.	6.63	....	99.97

Cordierite is orthorhombic (bipyramidal class), with the axial ratio .5871 : 1 : .5584. Its crystals are usually short columnar with an hexagonal habit due to the equal prominence of ∞P(110) and ∞P$\breve{\infty}$ (010). (Fig. 241). In addition to these planes, there are usually present also oP(001), P$\breve{\infty}$ (011) and ½P(112). The angle 110∧1$\bar{1}$0=60° 50′. Interpenetration twins, with ∞P(110) the twinning plane, are known but they are not common. Contact repeated twins, twinned parallel to the same plane, are more common. They usually possess a pseudohexagonal habit. The cleavage is good parallel to ∞P$\breve{\infty}$ (010) and there is often a parting parallel to the base (001).

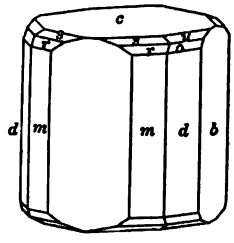


FIG. 241.—Cordierite Crystal with ∞P, 110 (*m*); ∞P$\bar{\infty}$, 011 (*a*); ∞P$\breve{\infty}$, 010 (*b*); ∞P$\breve{3}$, 130 (*d*); oP, 001 (*c*); P, 111 (*r*); ½P, 112 (*s*); ¾P$\breve{3}$, 134 (*u*) and 3P$\breve{3}$, 131 (*o*).

When in fresh condition the mineral has a glassy luster and a bluish, yellowish or grayish tinge by reflected light. It is transparent or translucent and colored varieties are strongly trichroic in dark blue, green and grayish yellow shades, which become more intense upon heating. Its hardness is 7–7.5 and sp. gr. = 2.63. Its refractive indices vary with the composition. In specimens from Ceylon, $\alpha = 1.5918$, $\beta = 1.5970$, $\gamma = 1.5992$.

Before the blowpipe cordierite is difficultly fusible. It is very slightly attacked by acids, but is completely decomposed when fused with alkaline carbonates.

The mineral is distinguished from *quartz* most easily by its cleavage and crystallization.

Cordierite weathers readily into fibrous or scaly aggregates of micaceous minerals yielding well defined pseudomorphs. The end product of the alteration is a muscovite, or a mixture of this mineral and biotite. Several of the alteration products are so characteristic that they have received distinct names. Among these are *chlorophyllite*, a green chloritic mineral; *fahlunite*, a serpentine-like mass; *gigantolite*, a brown, gray or green micaceous aggregate in large 12-sided prisms made up of thick plates; and *pinite*, a dark green aggregate forming prisms that are platy parallel to the base.

Synthesis.—Crystals of cordierite have been produced by fusing its constituents in an open crucible and then cooling the mass very slowly, but since the result was an anhydrous product its identity with cordierite is doubtful.

Occurrence.—Cordierite occurs as crystals embedded in gneiss,

schists, granite, quartz porphyries, and rhyolitic and andesitic lavas. It occurs both as a pyrogenetic mineral and as a product of contact metamorphism.

Uses.—Cordierite is used to some extent as a gem.

Localities.—Good crystals of cordierite are found in gneiss in Bodenmais, Bavaria, and at Arendal and other points in Norway; in the volcanic bombs thrown out by the volcanoes of the Lake Laach district in Prussia, and the volcano Asama Yama, in Japan, and in the andesite at Cabo de Gata, Almeria, Spain. It occurs also in granite veins at Haddam and near Norwich, in Connecticut; in gneiss, at Guilford, in the same State; at Bromfield, Mass., and near Richmond and Unity in New Hampshire.

CHAPTER XX

THE SILICATES—*Continued*

THE HYDRATED SILICATES

Chrysocolla ($H_2CuSiO_4 \cdot H_2O$, or $CuSiO_3 \cdot 2H_2O$)

CHRYSOCOLLA occurs usually in dense masses without any sign of crystallization; but at several places it has been found in spherulitic forms that are made up of fibers that are apparently acicular crystals. The symmetry of these, however, is unknown. The general view is that the mineral is colloidal.

The theoretical composition of chrysocolla, corresponding to the formula given above, and the analysis of a specimen from the Old Dominion Mine, in Arizona, are given below:

	SiO_2	CuO	Fe_2O_3	Al_2O_3	Mn_2O_3	H_2O	Total
Theoretical..	34.23	45.23	...	....	....	20.541	00.00
Globe, Ariz..	31.58	30.28	.84	6.27	2.22	28.71	99.90

Many analyses show the presence of MgO, CaO and FeO, and some the presence of ZnO.

The various analyses that have been recorded vary so widely, especially in the determinations of water, that the true composition of the mineral is still in doubt. It is possibly a solid solution of colloids.

An analysis of a specimen from Huiquintipa, Chile, which is thought to have been exceptionably pure gave:

SiO_2	Al_2O_3	CuO	FeO	CaO	MgO	H_2O	Total
46.14	.58	28.85	1.38	1.64	.83	20.15	99.57

This corresponds to the formula $H_3(Cu \cdot OH)(SiO_3)_2 \cdot H_2O$. The specimen was a turquoise blue enamel, with a hardness of 3.5 and a sp. gr. $= 2.532$.

Chrysocolla has an opal-like or earthy structure. It is green or turquoise blue and translucent. Its streak is greenish white. Impure varieties may be brown or black and have a dark brown or dark green

streak. It has a conchoidal fracture and is brittle. Its hardness varies between 2 and 4 and its density between 2 and 2.2.

The mineral is infusible before the blowpipe, but it colors the flame green. It yields water in the closed tube and is decomposed by HCl with the production of pulverulent silica.

It is distinguished from other green and blue silicates by its reaction toward HCl and the green flame it imparts to the blowpipe flame.

Occurrence.—Chrysocolla is produced by the oxidation of copper compounds and combination of these oxidation products with silicic acid in the upper portions of ore veins. It sometimes replaces other minerals, as atacamite, cerussite and labradorite and forms pseudomorphs after them.

Uses.—Chrysocolla is mined with other ores of copper and is treated with them for the metal it contains. Exact statistics of the quantity produced are not obtainable.

Localities.—The mineral occurs in many copper mines, especially in Bohemia, Hungary, Italy and Russia. It occurs as blue crusts on the basalts near Somerville, N. J.; as a bluish green matrix cementing black masses at the Old Dominion Copper Mine, Globe, Ariz.; and intimately intergrown with opal at the Boleo Mine, California. It is also abundant in Chile, where it occurs in all varieties.

Glauconite [Hydrous Silicate of Iron and Potassium]

Glauconite, or greensand, is an important constituent of some sediments. It is probably a mixture of several substances, of which the compound $FeK(SiO_3)_2 \cdot xH_2O$ may be most essential. It occurs as little round grains and pellets, mixed with the shells of foraminifera, forming beds of sand, and also as a component of limestone, marl, clay and sandstone. Glauconitic sands, because of their richness in potash were formerly used as fertilizers in the regions in which they are found.

Analyses of glauconite grains from Ashgrove, near Elgin, in Scotland (I), and of glauconite sand from Antwerp, Belgium (II), are as follows:

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O	Total
I.	49.09	15.21	10.56	3.06	2.65	.55	1.21	6.05	11.64	100.02
II.	50.42	4.79	19.90	5.96	2.28	3.21	.21	7.87	5.28	99.92

Glauconite is blackish, or yellowish green, in color, with a light green streak. It resembles earthy chlorite, but is probably amorphous. Its hardness is 2 and its density 2.2–2.8. It is opaque.

The mineral fuses with difficulty to a black magnetic slag and is decomposed in part by strong hydrochloric acid, but after fusion is completely dissolved with the separation of gelatinous silica. It yields water in the closed tube.

Occurrence and Localities.—Glauconite occurs in oceanic deposits and in sedimentary rocks of nearly all geological ages. Its principal occurrences in this country are in the belt of cretaceous beds on the Atlantic coastal plain. It is best known from the coastal portions of New Jersey and from Spotsylvania and Stafford Counties, in Virginia. It apparently occurs also as a decomposition product of augite in certain basaltic rocks. In all cases it appears to have been produced by secondary processes, *viz.*, by the absorption of potassium compounds and soluble silica by colloidal ferric hydroxide. In the ocean these compounds result from the action of decaying animal matter upon ferruginous clays and fragments of potassic silicates in rocks; when of later origin than the rocks themselves, by the action of solutions of potassic salts upon iron hydroxids.

Greenalite differs from glauconite in containing no potassium. It may be a hydrated ferrous silicate ($FeSiO_3 \cdot xH_2O$) or a ferrous-ferric silicate ($Fe_2Fe_3(SiO_4)_3 \cdot 3H_2O$). It occurs as round grains in the cherts of the Lake Superior region, and in its physical properties it closely resembles the glauconite granules in rocks. It is believed to be the source of the hematite ores of the district.

Apophyllite ($H_7KCa_4(SiO_3)_8 \cdot 4\frac{1}{2}H_2O$)

Apophyllite differs from the zeolites (p. 445) in containing no aluminia and in having some of its water replaced by fluorine; but in its general appearance and its manner of occurrence it is like them. The calculated composition corresponding to the formula usually assigned to the mineral is given in I. Analysis II is of a specimen from Bergen Hill, N. J., and III of a specimen from Golden, Colo. Some specimens contain also small quantities of ammonia.

	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	K_2O	H_2O	Fl	Total
I.	53.7	....	...	25.0	...	5.2	16.1	....	100.00
II.	52.24	....	...	25.03	...	4.05	16.61	2.21	100.14
III.	51.89	1.54	.13	24.51	.59	3.81	16.52	1.70	100.69

The mineral is tetragonal (ditetragonal bipyramidal class), with $a : b : c = 1 : 1.2464$. Its crystals usually contain the forms $\infty P \infty$ (100),

P(111) and oP(001), and often ∞P3(310) or ∞P2(210). In addition, about 55 other forms have been identified, but most of them are rare. Many of these are vicinal planes with large parameters. The crystals are of four types, (1) pyramidal with P(111) predominating; (2) prismatic with ∞P∞ (100) and P(111), the former predominating; (Fig. 242A), (3) cubical, with ∞P (100) and oP(001) equally prominent (Fig. 242B), and (4) tabular parallel to oP(001) (Fig. 242C). Twinning parallel to P(111) is rare. The angle $111 \wedge 1\bar{1}\bar{1} = 76°$. The mineral also occurs in granular and lamellar masses.

Apophyllite is glassy on fracture surfaces and most crystal faces, but on oP(001) it is distinctly pearly. It is white, grayish, flesh-colored or red, and transparent. Its streak is white. It possesses a very perfect cleavage parallel to oP(001) and a less perfect one parallel to ∞P(110).

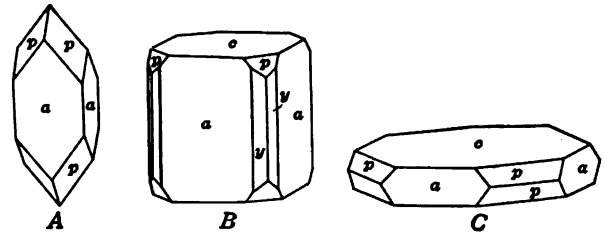


FIG. 242.—Apophyllite Crystals with ∞P∞ . 100 (*a*); P, 111 (*p*), oP, 001 (*c*) and ∞P3, 310 (*y*). A. Prismatic. B. Cubical. C. Tabular.

It is brittle. Its hardness is 4.5–5 and its density 2.2–2.4. It is strongly pyroelectric. For yellow light, $\omega = 1.5356$, $\epsilon = 1.5368$.

Before the blowpipe apophyllite exfoliates and fuses easily to a blebby white enamel, and imparts a violet color to the flame near the assay. In the closed tube it loses water and becomes opaque. It also loses water upon being pulverized. Most specimens give the reaction for fluorine. Half the water is lost at a comparatively low temperature (240°–260°), but the last remnant of the remainder is driven off only at a red heat. At 400° fluorine begins to escape. The mineral dissolves in HCl with the separation of slimy silica. At 180°–190°, under a pressure of 10–12 atmospheres, it dissolves in water, and from this solution it crystallizes upon cooling.

Apophyllite is recognized by its crystallization, its pearly luster on the basal plane, and its fluorine reaction.

Syntheses.—Apophyllite crystals have been obtained from solutions of its constituents in water containing CO_2, heated in a closed tube to 150–160°. They have also been formed by the action of a solution of

potassium silicate on gypsum. The mineral has also been described from the ruins of old Roman masonry around hot springs.

Occurrence.—The mineral occurs in the cavities of volcanic rocks, in veins in granite and gneiss and in ore veins and ore deposits in limestone. It is also found in the rocks surrounding hot springs. Under some conditions it alters to calcite, and to pectolite (p. 369).

Localities.—Good crystals of apophyllite occur at St. Andreasberg and Radauthal, Harz; at Striegau, Silesia; near Cipitbach, in the Seisser Alps, Tyrol; in the magnetite mines at Utö, Sweden; at Disko, Greenland; at many points in eastern Nova Scotia; at Bergen Hill, N. J.; at Table Mt., Golden, Colo., and at Santa Barbara, in Brazil.

THE ZEOLITES

The group known as the zeolites comprises minerals that are hydrous silicates of aluminium with calcium, sodium, potassium, barium or strontium. The calcium compounds are commonest, followed by the sodium compounds. Compounds with the other elements are comparatively rare.

While it is probable that some of them are primary products resulting from the cooling of a magma, in the great majority of cases the zeolites are secondary products derived by the alteration and hydration of alkali-aluminium silicates, such as the feldspars, leucite, nepheline, etc. They are nearly always found in veins, or on the walls of crevices in rocks (especially volcanic rocks), where they have been deposited by circulating water. They are commonly associated with calcite, pectolite, datolite or prehnite. All are well crystallized and some of them are in complicated crystals.

Many of the zeolites have been recrystallized from solutions in superheated water. The solutions having been produced by the action of various reagents upon aluminous silicates.

Before the blowpipe all the zeolites fuse with intumescence, or bubbling, and all give water in the closed tube. They are comparatively soft (3.5–5.5), and have a low specific gravity (2–2.4). The most common zeolites are:

Ptilolite	$(Ca \cdot K_2 \cdot Na_2)Al_2Si_{10}O_{24} \cdot 5H_2O$	
Heulandite	$H_4CaAl_2(SiO_3)_6 \cdot 3H_2O$	Monoclinic
Phillipsite	$(Ca \cdot K_2)Al_2(SiO_3)_4 \cdot 4\frac{1}{2}H_2O$	Monoclinic
Harmotome	$(H_2(Ba \cdot K_2)Al_2(SiO_3)_5 \cdot 5H_2O$	Monoclinic
Stilbite	$(Ca \cdot Na_2)Al_2Si_6O_{16} \cdot 6H_2O$	Monoclinic
Laumontite	$CaAl_2(SiO_3)_4 \cdot 4H_2O$	Monoclinic

Scolecite	$Ca(AlOH)_2(SiO_3)_3 \cdot 2H_2O$	Monoclinic
Natrolite	$Na_2Al(AlO)(SiO_3)_3 \cdot 2H_2O$	Orthorhombic
Thomsonite	$(Ca \cdot Na_2)Al_2(SiO_4)_2 \cdot 2\frac{1}{2}H_2O$	Orthorhombic
Chabazite	$(Ca \cdot Na_2)Al_2(SiO_3)_4 \cdot 6H_2O$	Hexagonal
Analcite	$NaAl(SiO_3)_2 \cdot H_2O$	Isometric

Ptilolite ($(Ca \cdot K_2 \cdot Na_2)Al_2Si_{10}O_{24} \cdot 5H_2O$) occurs in short, hairlike, white or colorless crystals, aggregated into delicate tufts or spongy masses. Their system of crystallization is unknown. Their luster is vitreous. The needles apparently have a cleavage perpendicular to their long axes. The mineral is scarcely acted upon by boiling hydrochloric acid.

The composition of ptilolite from Colorado is quoted as follows:

SiO_2	Al_2O_3	CaO	Na_2O	K_2O	H_2O	Total
70.35	11.90	3.87	.77	2.83	10.18	99.90

Its refractive indices are about 1.480.

The mineral is found in the cavities of a volcanic rock in Green and Table Mts., Jefferson Co., Colo.

Heulandite ($H_4CaAl_2(SiO_3)_6 \cdot 3H_2O$)

Heulandite occurs in monoclinic crystals (monoclinic prismatic class), with the axial ratio .4035 : 1 : .4293 and $\beta = 91° 25'$, in foliated and granular masses and in globular aggregates

The theoretical composition of heulandite (the formula of which may also be written $CaAl_2Si_6O_{16} \cdot 5H_2O$), and the analysis of a specimen from Anthracite Creek, Gunnison Co., Colo., are given below:

	SiO_2	Al_2O_3	CaO	Na_2O	K_2O	H_2O	Total
I.	59.22	16.79	9.20	...	...	14.79	100.00
II.	57.38	17.18	8.07	.82	.40	16.27	100.12

I. Theoretical.
II. Gunnison Co., Colo.

Its crystals are usually tabular parallel to $\infty P \breve{\infty}$ (010). Their most prominent forms are: $\infty P \breve{\infty}$ (010), $-2P \bar{\infty}$ (201), $2P \bar{\infty}$ ($\bar{2}01$), oP(001), ∞P(110), $2P \breve{\infty}$ (021) and P($\bar{1}11$) (Figs. 243 and 244). The angle $110 \wedge 1\bar{1}0 = 43° 56'$. Twins are known, with oP(001) the twinning plane. The cleavage is perfect parallel to $\infty P \breve{\infty}$ (010) and the fracture is uneven or conchoidal.

The mineral has a glassy luster, which becomes pearly on $\infty P \breve{\infty}$ (010).

It is colorless, white, yellow, brown, pink or red. Its streak is white. It is brittle, has a hardness of 3–4 and a density of 2.2. For yellow light, $\alpha = 1.4998$, $\beta = 1.5003$, $\gamma = 1.5070$.

Before the blowpipe heulandite whitens, exfoliates, crinkles and melts to a white glass. It yields water in the closed glass tube and becomes dull and opaque. It is decomposed by hydrochloric acid with precipitation of pulverulent or gelatinous silica. Its powder reacts alkaline.

Heulandite is distinguished by its crystallization and its reactions before the blowpipe.

Synthesis.—Crystals have been made by heating anorthite powder to 200° with gelatinous silica in water containing carbon dioxide.

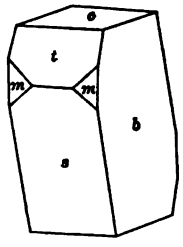


FIG. 243.

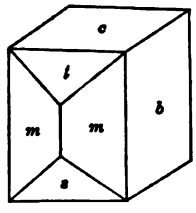


FIG. 244.

FIG. 243.—Heulandite Crystal with $\infty P \bar{\infty}$, 010 (*b*); ∞P, 110 (*m*); $2P \bar{\infty}$, $\bar{2}01$ (*s*); $-2P \bar{\infty}$, 201 (*t*) and oP, 001 (*c*).

FIG. 244.—Heulandite, var. Beaumontite. Forms same as in Fig. 243.

Occurrence.—The mineral occurs in the cavities of porous basalts, and occasionally in gneisses and granites, associated with other zeolites. It is found also in some ore veins.

Localities.—Good crystals occur in the druses and veins in volcanic rocks at Fassa, Tyrol; at Montecchio Maggiore, Italy; at Lake Mien, Sweden; and along the north shore of Lake Superior. It also occurs in druses in gneisses at the Campsie Hills, Scotland, and at Jones Falls quarries (*beaumontite*), Baltimore, Md.

Phillipsite $((Ca \cdot K_2)Al_2(SiO_3)_4 \cdot 4\frac{1}{2}H_2O)$

Phillipsite is a calcium, potassium alumino-silicate with the theoretical composition indicated in line I. The composition of a specimen from Richmond, Australia, is shown in line II. Many specimens contain barium and sodium.

	SiO_2	Al_2O_3	CaO	Na_2O	K_2O	H_2O	Total
I.	48.8	20.7	7.6	....	6.4	16.5	100.00
II.	45.60	22.70	4.52	4.51	6.05	16.62	100.00

The mineral crystallizes in the monoclinic system with the axial ratio .7095 : 1 : 1.2563 and $\beta = 124° 23'$. Its crystals are never simple but are always twinned parallel to oP(001), forming groups with an orthorhombic or tetragonal habit (Fig. 245). These are often twinned again with P $\breve{\infty}$ (011) the twinning plane, producing interpenetration fourlings (Fig. 246A). Three fourlings twinned again, with ∞ P(110) the twinning plane, result in a group of 12 individuals (Fig. 246B). The individual crystals are usually bounded by oP(001), ∞ P $\breve{\infty}$ (010) and ∞ P(110),

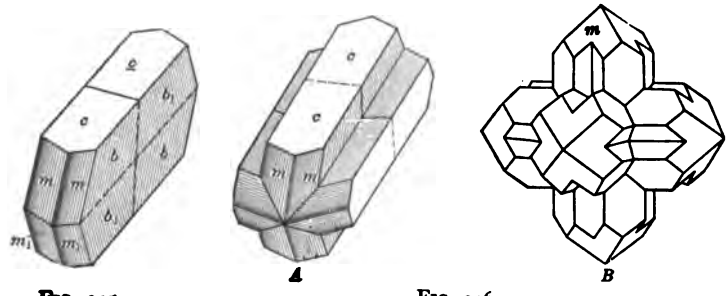


FIG. 245. FIG. 246.

FIG. 245.—Phillipsite Interpenetration Twin about oP(001). Forms are oP, 001 (*c*); ∞ P $\breve{\infty}$, 010 (*b*) and ∞ P, 110 (*m*).

FIG. 246.—Phillipsite.—A. Fourling of two twins like Fig. 245 twinned again about P $\breve{\infty}$ (011). The *c* faces are on the outside. B. Three fourlings twinned about ∞ P(110).

though ∞ P $\bar{\infty}$ (100), ∞ P$\bar{2}$(120) and several other forms also occur on them. The angle $110 \wedge 1\bar{1}0 = 60° 42'$. The faces ∞ P(110) and ∞ P $\breve{\infty}$ (010) are usually striated parallel to the edge between the two. Besides occurring in distinct crystals the mineral is also found in radially fibrous globular aggregates.

Phillipsite has a glassy luster; is colorless or white, yellowish, grayish, reddish or bluish; is transparent or translucent and has a white streak. Its cleavage is distinct parallel to oP(001) and ∞ P $\breve{\infty}$ (010). It is brittle, has a hardness of 4 and a density of 2.2. Its refractive index, $\beta = 1.51$.

Before the blowpipe it fuses to a white glass. In the closed glass tube it gives off water and becomes cloudy and milky. It is decomposed in HCl with the separation of gelatinous silica, and in dilute H_2SO_4 without precipitation.

It is distinguished by its crystallization and by the fact that it dissolves in H_2SO_4 without precipitation of $BaSO_4$ (see Harmotome, below).

Synthesis.—Crystals of phillipsite have been produced by heating potassium aluminate and silicate in a closed glass tube at 200°.

Localities.—The mineral occurs in the vacuoles of basic igneous rocks at the Giant's Causeway, Ireland; at Capo di Bové, near Rome, Italy; at Aci Castello, in Sicily, and at various points in the state of Victoria, Australia.

Harmotome ($H_2(Ba \cdot K_2)Al_2(SiO_3)_5 \cdot 5H_2O$)

Harmotome is a barium compound almost identical in crystallization with phillipsite.

Its theoretical (I) composition (also written $(Ba \cdot K_2)Al_2Si_5O_{14} \cdot 5H_2O$) and the analysis of a specimen (II) from Thunder Bay, Canada, are shown below.

	SiO_2	Al_2O_3	CaO	BaO	H_2O	Total
I.	46.64	15.78	....	23.67	13.91	100.00
II.	46.36	17.16	2.25	21.18	14.54	101.49

The crystallization and twinning of harmotome are the same as in phillipsite. Its axial ratio is .7032 : 1 : 1.2310, with $\beta = 124° 50'$. The crystals more commonly contain the form $\infty P \bar{\infty}$ (100), and a few more orthodomes. Fourlings are common, but in these the planes $\infty P \breve{\infty}$ (010) form the outside of the group, whereas in phillipsite the outside planes are oP(001). The planes ∞P(110) and $\infty P \breve{\infty}$ (010) are striated as in phillipsite (Fig. 247).

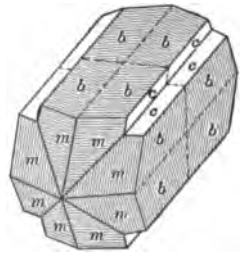


FIG. 247.—Harmotome Fourling Twinned like Phillipsite, Fig. 246 A, Except that Commonly the *b* Faces are on the Outside. Note differences in directions of striations on this figure and 246 A.

In general appearance and physical properties harmotome resembles phillipsite. It has, however, but one distinct cleavage, which is parallel to $\infty P \breve{\infty}$ (010). Its hardness is 4–5 and density 2.5. Its refractive indices are: $\alpha = 1.503$, $\gamma = 1.508$. It acts very much like phillipsite before the blowpipe and in the closed tube. It, however, dissolves readily in HCl with the separation of pulverulent silica, and in dilute H_2SO_4 with precipitation of $BaSO_4$. Its powder reacts weakly alkaline.

The mineral is distinguished from all others but *phillipsite* by its crystallization, and from this mineral by its reaction with H_2SO_4.

It occurs in the vacuoles of volcanic rocks, in gneisses, granitic rocks and a few ore veins.

Localities.—It is found at St. Andreasberg in Harz; in veins in granite at Strontian, in Scotland; in druses in the syenite near Christiania, Norway; on calcite in mines at Rabbit Mt., and in the Beaver Mine, near Thunder Bay, Ontario; and in the gneiss under New York City.

Stilbite $(Ca \cdot Na_2)Al_2Si_6O_{16} \cdot 6H_2O)$

Stilbite, or desmine, is found in twinned crystals with an orthorhombic habit resembling the simple twins of phillipsite, and in sheaf-

FIG. 248.—Sheaf-like Aggregates of Stilbite.

like aggregates (Fig. 248), in radiating bundles and in thin platy prisms.

Its composition calculated from the formula given above is as in I. The result of the analysis of a soda-free specimen from French Creek Mines, Pa., is given in II and of a sodium-bearing specimen from Golden, Colo., in III.

	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	H_2O	Total
I.	57.4	16.3	7.7	....	1.4	....	17.2	100.00
II.	58.00	13.40	7.80	1.40	tr.	1.03	18.30	99.93
III.	54.67	16.78	7.98	....	1.47	....	19.16	100.06

The crystals are monoclinic (prismatic class), with an axial ratio of .7623 : 1 : 1.1940, with $\beta = 129° 10'$. They are always interpenetration twins, with oP(001) the twinning plane as in phillipsite. The individ-

uals are simple combinations of $\infty P\bar{\infty}$ (010), oP(001) and ∞P(110), and they are usually tabular parallel to $\infty P\bar{\infty}$ (010). Their cleavage is perfect parallel to $\infty P\bar{\infty}$ (010) and imperfect parallel to oP(001).

Stilbite is colorless or white, grayish, greenish, yellowish, red or brown. It has a white streak and a glassy luster that is nearly pearly on $\infty P\bar{\infty}$ (010). It is transparent or translucent, is brittle, has a hardness of 3–4 and a density of 2.2. Its refractive indices are: $\alpha=1.494$, $\beta=1.498$, $\gamma=1.500$.

Before the blowpipe it exfoliates, swells and crinkles to a white blebby glass. In the closed tube it yields water and becomes cloudy and opaque. It is decomposed by HCl with the production of pulverulent silica. Its powder reacts alkaline.

Occurrence.—Stilbite occurs in the vacuoles of amygdaloidal basalts, in veins cutting granites and other coarse-grained rocks, and on the walls of cracks in gneisses and schists. It occurs also as deposits around hot springs.

Localities.—Its principal localities are the basalt rocks of the Isle of Skye, Arran in Scotland; Mourne Mts. and the Giant's Causeway, in Ireland; and the Deccan, in India. It occurs in veins at Radauthal in the Harz; at Striegau, in Silesia; and at Falun, in Sweden. It is abundant in the old volcanic rocks of Nova Scotia; of Lake Superior, and of Table Mt., near Golden, Colo., and near Bergen Hill, N. J., and is present in cavities in gneisses at several points in Connecticut and Pennsylvania.

Laumontite ($CaAl_2(SiO_3)_4 \cdot 4H_2O$)

Laumontite occurs in monoclinic crystals and in radiating fibrous aggregates. Its formula demands the composition shown in I. The analysis of a specimen from Table Mt., Colo., is quoted in II.

	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	K_2O	H_2O	Total
I.	51.07	21.72	...	11.90	...	...	15.31	100.00
II.	51.43	21.52	.94	11.88	.19	.35	13.81	100.12

Its crystals are usually very simple monoclinic (prismatic class), combinations with an axial ratio 1.1451 : 1 : .5906 with $\beta=99° 18'$. The most common forms observed are ∞P(110) and $2P\bar{\infty}$ ($\bar{2}01$), and often these are the only two present (Fig. 249). Frequently crystals of this type are twinned parallel to $\infty P\bar{\infty}$ (100). Their cleavage is perfect parallel to $\infty P\bar{\infty}$ (010) and ∞P(110). The value $111 \wedge 1\bar{1}0=93° 44'$.

Laumontite is white, grayish, yellowish or reddish, and has a glassy

luster except on cleavage surfaces. On these it is pearly. It is transparent or translucent and its streak is white. It is brittle, has a hardness of 3-3.5 and a density of 2.3-2.4. Its refractive indices are: $\alpha=1,513$, $\beta=1,524$, $\gamma=1,525$.

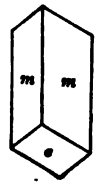


FIG. 249.—Laumontite Crystal with ∞P, 110 (*m*) and $2P\bar{\infty}$, $\bar{2}01$ (*e*).

Before the blowpipe it swells and melts to a white glass. It gelatinizes with HCl. It readily yields some water at low temperature in a closed tube, but a red heat is required to drive off the last traces. When melted and cooled the glass crystallizes to anorthite and a pyroxene mineral.

Laumontite is best recognized by its crystals.

Occurrence.—It occurs in the cavities of basic volcanic rocks. It is also found in veins in clay slates, and schists and as a gangue mineral in certain ore veins.

Localities.—Its best known localities are the Isle of Skye and Dumbartonshire, in Scotland; in the Zillerthal, Tyrol; at Table Mt., Colo.; at Bergen Hill, N. J.; at many points on the north shore of Lake Superior, and on Keweenaw Point, on the south shore, and in the trap rocks near Annapolis, Nova Scotia.

Scolecite ($Ca(AlOH)_2(SiO_3)_3 \cdot 2H_2O$)

Scolecite is white and it occurs in silky, fibrous and dense radiating masses and also in crystals that are often aggregated into divergent groups (Fig. 250).

Its formula (written also $CaAl_2Si_3O_{10}.3H_2O$), demands the composition indicated in I. The analysis of a specimen from Table Mt., Colo., is quoted in II.

	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	K_2O	H_2O	Total
I.	45.92	26.05	...	14.27	....	...	13.75	100.00
II.	46.03	25.28	.27	12.77	1.04	.13	14.48	100.00

The mineral is monoclinic (domatic class), with $a : b : c = .9764 : 1 : .3434$ and $\beta = 90° 42'$. Its crystals are columnar or acicular in the direction of *c* and are usually bounded by $\infty P\bar{\infty}$ (010), ∞P(110), $-P$(111) and $P(\bar{1}11)$ (Fig. 251). Other planes are sometimes present in the prismatic zone, and $-P\bar{\infty}$ (101), $-3P$(331) and $-3P\bar{3}$(131) at the terminations. Twins are more common than simple crystals, the twinning plane being $\infty P\bar{\infty}$ (100) and the composition plane the same. The angle $110 \wedge 1\bar{1}0 = 88° 37'$.

Scolecite is glassy in luster, transparent or translucent, and colorless or white. Its cleavage is perfect parallel to ∞P(110) and its fracture

FIG. 250.—Divergent Groups of Scolecite Crystals from near Bombay, India.

conchoidal or uneven. Its hardness is 5–5.5 and density 2.2–2.4. Its crystals are strongly pyroelectric. On a cooling crystal the front prismatic faces (110) are positively charged and the corresponding back faces ($1\bar{1}0$) negatively charged. Their hemihedrism is brought out clearly by etch figures. The refractive indices for yellow light are: $\alpha = 1.5122$, $\beta = 1.5187$, $\gamma = 1.5194$.

Before the blowpipe scolecite crinkles and fuses to a white blebby enamel. In the closed tube it yields water and becomes white and opaque. It gelatinizes with acids.

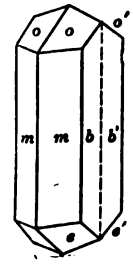


FIG. 251.—Scolecite Crystal with ∞P, 110 (*m*); ∞P$\bar{\infty}$010 (*b*); P, $\bar{1}11$ (*e*), and −P, 111 (*o*). Twinned about ∞P$\bar{\infty}$ (100).

Scolecite is distinguished by its crystallization.

Synthesis.—Scolecite has been obtained by treating natrolite (p. 454) with a solution of $CaCl_2$. Crystals occur on Roman tiles that have been exposed for centuries to the waters of the hot springs at Plombières, France.

Occurrence.—It occurs in the cavities of basic volcanic rocks and in veins in crystalline schists.

Localities.—Its principal occurrences are veins in siliceous rocks in Canton Uri, Switzerland; and in the cavities of basalts in the Bern Fjord, Iceland; at Staffa and the Isle of Mull, Scotland; at Table Mountain, near Golden, Colo.; and in the Deccan, India.

Natrolite ($Na_2Al(AlO)(SiO_3)_3 \cdot 2H_2O$)

Natrolite occurs in acicular crystals, and in radial fibrous, granular and dense masses.

Its theoretical composition (I) and the analysis of a specimen (II) from Magnet Cove, Ark., correspond very closely.

	SiO_2	Al_2O_3	FeO	CaO	MgO	Na_2O	H_2O	Total
I.	47.36	26.86	...	...	...	16.32	9.46	100.00
II.	47.56	26.82	.20	.13	.09	15.40	9.63	99.83

Natrolite is orthorhombic (bipyramidal class), with $a : b : c = .9785 : 1 : .3536$ and $\infty P(110)$, $\infty P\bar{\infty}(101)$, $\infty P\breve{2}(120)$, $\infty P\breve{\infty}(010)$, $P(111)$ the most commonly occurring forms (Fig. 252). Additional forms that are fairly common are $P\frac{11}{10}$ (11.10.11), $3P(331)$ and $3P\breve{3}(131)$.

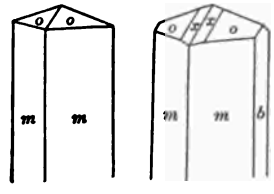


FIG. 252.—Natrolite Crystals with ∞P, 110 (*m*); P, 111 (*o*); $\infty P\breve{\infty}$, 010 (*b*) and $P\frac{11}{10}$, 11.10.11 (*x*).

The prismatic angle is nearly 90° (88° 45′), causing the crystals to appear tetragonal. Some crystals are apparently monoclinic (prismatic class) with $\beta = 90°\ 5'$, in which case the substance is dimorphous. The habit of the crystals is columnar, or acicular, in the direction of the *c* axis with striations on the prismatic planes parallel to this direction. In the case of a few crystals from Norway, however, the elongation is in the direction of *b*. Twins are known, with $3P\bar{\infty}$ (301) the twinning plane.

Natrolite is glassy and transparent or translucent. It is colorless or white, yellowish, reddish or green. Its streak is white. Its cleavage is perfect parallel to $\infty P(110)$. Its fracture is uneven or conchoidal, its hardness 5–5.5 and density 2.2–2.5. Its refractive indices for yellow light are: $\alpha = 1.4754$, $\beta = 1.4790$, $\gamma = 1.4887$.

Before the blowpipe the mineral fuses quietly to a colorless glass at the same time coloring the flame yellow. In the closed tube it loses water and becomes cloudy and opaque. Its powder reacts alkaline.

Natrolite is easily distinguished from other zeolites by its crystallization and action before the blowpipe.

Syntheses.—Crystals of natrolite have been obtained by dissolving

the powdered mineral in a closed tube with carbonated water at 160° and cooling. Crystals supposed to be those of natrolite have been produced by treating nepheline in a closed tube at 200° with a solution of alkaline carbonates in carbonated water.

Occurrence.—The mineral occurs in the cavities of volcanic rocks, and as an alteration product of nepheline, sodalite and plagioclase in coarse-grained rocks.

Localities.—Crystallized natrolite is abundant in the volcanic rocks of Hegau and the Kaiserstuhl in Baden, in the basalts of Silesia and Bohemia, in the volcanic rocks of Tyrol and Italy; in those of the Auvergne, France; in veins in the syenites of Langesundfjörd, in Norway; in the basalts of Cape Blomidon and other points in Nova Scotia; at Eagle River, in Michigan; and Bergen Hill, N. J.; and in the nepheline syenites of Magnet Cove, Ark., and elsewhere.

Thomsonite $((Ca \cdot Na_2)Al_2(SiO_4)_2 \cdot 2\frac{1}{2}H_2O)$

Thomsonite, or comptonite, is evidently an isomorphous mixture of soda and lime molecules—the ratio of Ca to Na_2 varying between 3 : 1 and 1 : 1. The calculated composition represented by the formula $(Ca \cdot Na_2)Al_2(SiO_4)_2 \cdot 2\frac{1}{2}H_2O$ is given in III. In I is given the calculated formula of the compound in which Ca : Na_2 is as 3 : 1 and in II, that in which this ratio is 2 : 1. The analysis of tabular crystals from the basalt of Table Mt., near Golden, Colo., is given in IV.

	SiO_2	Al_2O_3	CaO	Na_2O	H_2O	Total
I.	37.0	31.4	12.9	4.8	13.9	100.00
II.	36.9	31.4	11.5	6.4	13.8	100.00
III.	36.8	31.3	8.6	9.5	13.8	100.00
IV.	40.68	30.12	11.92	4.44	12.86	100.02

Thomsonite crystallizes in the orthorhombic system with $a : b : c =$ .9932 : 1 : 1.0066. The crystals, which are rare, usually have a prismatic habit. They are bounded by $\infty P \bar{\infty}$ (100), ∞P(110), $\infty P \breve{\infty}$ (010) oP(001), $4P \bar{\infty}$ (401), $8P \bar{\infty}$ (801), and often $\frac{1}{2}P \breve{\infty}$ (012), and are striated parallel to c (Fig. 253). The angle $110 \wedge 1\bar{1}0 = 89° 37'$. The crystals are commonly grouped in radial aggregates or spherical concretions. Rarely, the mineral is in fine-grained structureless masses.

Thomsonite has a glassy luster that in some cases is slightly pearly, especially on cleavage planes. It is transparent or translucent, colorless, white, gray, green or red and has a colorless streak. Some radial aggregates are red and white in concentric zones. The cleavage of thom-

sonite is perfect parallel to $\infty P \breve{\infty}$ (010) and less perfect parallel to $\infty P \bar{\infty}$ (100). Its fracture is uneven. It is brittle, has a hardness of 5–5.5 and a density of 2.3–2.4, and is pyroelectric. Its refractive indices are: $\alpha = 1.498$, $\beta = 1.503$, $\gamma = 1.525$.

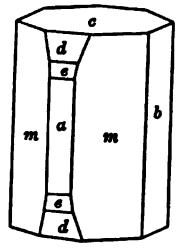


FIG. 253.—Thomsonite Crystal with ∞ P. 110 (*m*); $\infty P \bar{\infty}$, 100 (*a*); $\infty P \breve{\infty}$, 010 (*b*); $8P \bar{\infty}$, 801 (*e*); $4P \bar{\infty}$, 401 (*d*) and oP, 001 (*c*).

Before the blowpipe it swells and fuses to a white glass. In the closed tube it gives up water and becomes opaque. It gelatinizes with HCl. Its powder reacts alkaline.

Lintonite is a green, prehnite-like variety occurring as little structureless pebbles on the north shore of Lake Superior. It is used to some extent as a gem stone. Its hardness is 5–6, and its sp. gr. 2.34.

Chlorastrolite is a fibrous variety, also occurring as pebbles on the shores of Lake Superior, especially on Isle Royale. It is often pink and white in concentric zones. It also is employed as an ornamental stone. Some of the chlorastrolite is probably fibrous prehnite.

Occurrence.—The mineral occurs in the vacuoles in igneous rocks, as a constituent of pegmatite dikes, and as an alteration product of nepheline in nepheline rocks, and of the plagioclases in crystalline schists. It is found also as little pebbles on the north shore of Lake Superior, where it was washed from amygdaloidal basalts.

Localities.—It is found in the basalt of Kaaden and other places in Bohemia; in the porphyries of Kilpatrick, Kilmalcom and Port Glasgow, in Scotland; in the inclusions in the lavas of Mte. Somma, near Naples, Italy; in veins on Låven, Arö and at other places in Norway; in the basalts at Port George and Cape Split in Nova Scotia; on the shore of Lake Superior near Grand Marais, Minnesota, where it originally filled amygdaloidal cavities in diabases and basalts; in cavities in the nepheline syenites at Magnet Cove, Ark.; and in the basalt at Table Mt. near Golden, Colo.

Production.—Chlorastrolite to the value of $350 was sold during 1912.

Chabazite ($(Ca \cdot Na_2)Al_2(SiO_3)_4 \cdot 6H_2O$)

Chabazite has a variable composition. It is probably an isomorphous mixture of the Ca, Na and K molecules corresponding to the general formula $(R''R'_2)Al_2(SiO_3)_4 \cdot 6H_2O$. Analyses of the three chemical types of the mineral are given below.

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	H_2O	Total
I.	43.84	20.99	...	5.89	...	5.78	1.83	21.97	100.30
II.	47.52	19.48	...	9.63	...	.52	.36	22.11	100.05
III.	49.24	18.07	.84	5.16	.86	....	3.00	21.31	99.95

I. Phacolite from Richmond, Victoria.
II. From the basalt of Table Mt., Golden, Colo. Also .43 SrO.
III. Haydenite from Jones Falls quarry, Baltimore, Md. Also 1.47 BaO.

Chabazite occurs in crystals and in compact aggregates. It crystallizes in the rhombohedral division of the hexagonal system (ditrigonal scalenohedral class), with $a : c = 1 : 1.0860$. Crystals are usually of a cubical habit because of the predominance of the rhombohedron which

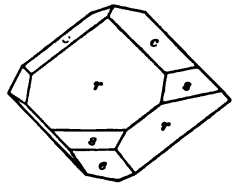


FIG. 254.

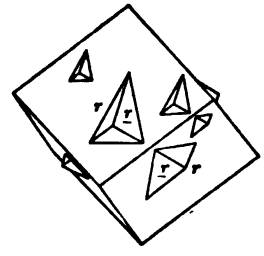


FIG. 255.

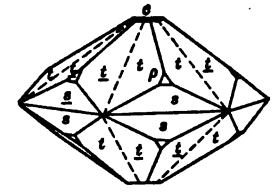


FIG. 256.

FIG. 254—Chabazite Crystal with R, $10\bar{1}1$ (r); $-\frac{1}{2}$R, $01\bar{1}2$ (e) and -2R, $02\bar{2}1$ (s).

FIG. 255.—Chabazite Interpenetration Twin, with c the Twinning Axis and oR(0001) the Twinning Plane.

FIG. 256.—Phacolite with Same Forms as in Fig. 254 and also oR, 0001 (c); $\frac{2}{3}$P2, $11\bar{2}3$ (t) and $-\frac{2}{3}$R, $02\bar{2}3$ (ρ). Interpenetration twin about oR(0001).

has nearly equal a and c axes. Besides R($10\bar{1}1$), the most common forms are oR(0001), $-\frac{1}{2}$R($01\bar{1}2$ and -2R($02\bar{2}1$) (Fig. 254), though other minus rhombohedrons, scalenohedrons and a prism (∞P2, $11\bar{2}0$) and pyramid ($\frac{2}{3}$P2, $11\bar{2}3$) of the second order are also known. The angle $10\bar{1}1 \wedge \bar{1}101 = 85° 14'$. The crystals are often striated parallel to the edge between R and $-\frac{1}{2}$R. Twinning is not uncommon. Both contact and interpenetration twins are known, the former with R($10\bar{1}1$) the twinning plane, and the latter with oR(0001) the twinning plane (Fig. 255). In the variety of chabazite known as *phacolite*, the crystal habit is lenticular because of the nearly equal prominence of $\frac{2}{3}$P2($11\bar{2}3$) and -2R($02\bar{2}1$), and twinning parallel to oR (0001) (Fig. 256).

Chabazite is glassy in luster, is transparent or translucent, colorless or white, gray, yellowish or pink. Its streak is colorless. Its cleavage

is distinct parallel to R(10$\bar{1}$1) and its fracture uneven. Its hardness is 4–5 and density 2.08–2.16. Its indices of refraction are about 1.48.

Before the blowpipe fragments of the mineral usually swell and fuse to a porous translucent glass. In the closed tube they yield water and become cracked, but remain clear. The variety from Victoria (phacolite), however, becomes cloudy and red and breaks into pieces. The mineral is decomposed by HCl and the separation of slimy silica, but after fusion is insoluble. Its powder reacts weakly alkaline.

Chabazite is distinguished by its crystallization and its reaction in the closed tube.

Syntheses.—Chabazite crystals have been obtained by dissolving the powder of the mineral in carbonated water in a closed tube at 150° and cooling, and by heating to 200° a mixture of freshly precipitated SiO_2, Al_2O_3 and $Ca(OH)_2$ in water containing CO_2.

When chabazite is fused alone it crystallizes as anorthite.

Occurrence.—The mineral occurs in the vacuoles of basalts and other volcanic rocks and on the walls of crevices in gneisses and schists. It is found also in ore veins and as a deposit from thermal springs.

Localities.—It is abundant in nearly all regions in which basic volcanic rocks occur, especially in Rhenish Prussia; Hesse; Silesia; Bohemia; Tyrol; Italy; Canton Uri, Switzerland; Kilmalcolm and Skye, Scotland; Iceland; near Richmond, Victoria (phacolite), and elsewhere. In North America it occurs in the basalts in southwestern Nova Scotia; on the walls of clefts in a gneiss at Jones Falls and Baltimore, Md. (*haydenite*); and in the basalt of Table Mt. and Golden, Colo.

Analcite ($NaAl(SiO_3)_2 \cdot H_2O$)

Analcite corresponds to the monohydrate of a sodium leucite. Its formula demands the composition shown in I. In II is given the analysis of a specimen from Table Mt., Colo. Many analcites contain small quantities of CaO. In III is the analysis of calciferous crystals from the Highwoods Mts., Mont.

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	H_2O	Total
I.	54.54	23.20	....	....	...	14.09	....	8.17	100.00
II.	55.81	22.43	....	....	...	13.47	....	8.37	100.08
III.	54.90	23.30	tr.	1.90	.70	10.40	1.60	7.50	100.30

Analcite forms isometric crystals that are usually icositetrahedrons, 2O2(211) (Fig. 257). More rarely they are modified cubes (Fig. 258),

containing $\infty O \infty$ (100), ∞O(110), $2O \infty$ (210), $2O2$(211), O(111) and occasionally $\frac{3}{2}O$(332) and icositetrahedra with large parameters. Some crystals show double refraction which is regarded as due to strain.

The mineral has a glassy luster. It is transparent or translucent, colorless or white, gray, yellowish, greenish or reddish. Its streak is white. It possesses a very imperfect cleavage parallel to $\infty O \infty$ (100) and an uneven fracture. Its hardness is 5–5.5 and density 2.2–2.3. For yellow light, $n = 1.487$.

Before the blowpipe analcite fuses to a colorless glass, imparting a yellow color to the flame. In the closed tube it yields water, but retains its form and luster. It gelatinizes with HCl. Its powder reacts alkaline.

Analcite resembles leucite and light-colored transparent garnets. It is distinguished from *garnets* by its less hardness and from *leucite*

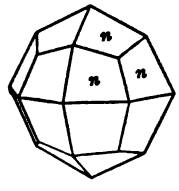


FIG. 257.

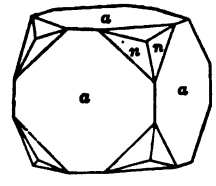


FIG. 258.

FIG. 257.—Analcite Crystal with $2O2$, 211 (*n*).
FIG. 258.—Analcite Crystal with $\infty O \infty$, 100 (*a*) and $2O2$, 211 (*n*).

by the presence of water and by its easy fusibility. It differs from *chabazite* by fusing without intumescence to a colorless glass.

Syntheses.—Crystals of analcite have been made by heating sodium silicate, or a hydrate, with an aluminous glass to 180°–190° in a closed tube, and by heating in a similar manner a mixture of sodium silicate and aluminate with limewater. Crystals have also been obtained by heating to 500° a mixture of finely powdered laumontite with an aqueous solution of sodium silicate.

Occurrence.—Analcite occurs as a primary constituent of certain alkaline volcanic rocks in the Little Belt and the Highwood Mts., Mont., and elsewhere. It occurs also filling cavities in volcanic lavas and as a secondary mineral, replacing nepheline, leucite and sodalite in both volcanic and plutonic rocks.

Localities.—It is found in the vacuoles of basalts on the Cyclopean Islands, near Catonia, Sicily; in the Kaiserstuhl, Baden; in the Seisser

Alps, Tyrol; at Dumbarton, Old Kilpatrick and elsewhere in Scotland; at Bergen Hill, N. J.; Table Mt. near Golden, Colo.; on Keweenaw Pt., Lake Superior; in southwestern Nova Scotia, and elsewhere. It occurs in veins in southern Norway; in druses near Richmond, Victoria, and as an original component of igneous rocks in the Highwood Mts., and the Little Belts Mts., in Montana; near Cripple Creek, Colo.; near Sydney, N. S. Wales; at Winchester, Mass., and elsewhere.

CHAPTER XXI

THE TITANATES AND TITANO-SILICATES

THE titanates are salts of titanium acids that are in all respects analogous to silicic acids. Thus, the normal titanate is a salt of the acid H_4TiO_4 and the metatitanate a salt of metatitanic acid ($H_4TiO_4 - H_2O = H_2TiO_3$). The mineral, *perovskite*, for instance, is a calcium metatitanate ($CaTiO_3$) and *ilmenite* a ferrous metatitanate. Dititanates are salts of $H_2Ti_2O_5$($2H_4TiO_4 - 3H_2O = H_2Ti_2O_5$). There are no dititanates known among minerals, but there is one mineral which is fairly common that may be regarded as a dititanate in which one of the Ti atoms has been replaced by Si, giving rise to a titano-silicate. This mineral is *sphene*, which is the calcium salt $CaSiTiO_5$.

Perovskite ($CaTiO_3$)

Perovskite occurs almost exclusively in small crystals with a cubic habit. Although apparently complexly modified cubes, they are in fact complicated intergrowths of orthorhombic lamellae, with $a : b : c = 1 : 1 : .7071$ (approximately).

The formula $CaTiO_3$ is equivalent to 41.1 per cent CaO and 58.9 per cent TiO_2, but the mineral usually contains also some Fe.

The cleavage of perovskite is cubic. Its fracture is uneven to conchoidal. It is brittle, has a hardness of 5.5 and density of 4.02. Its color varies from pale yellow through orange-yellow to reddish brown and grayish black. Its streak is colorless and luster adamantine. The mineral is transparent to opaque. Its refractive indices for yellow light are about 2.38.

Perovskite is infusible in the blowpipe flame. The salt of phosphorus bead in the oxidizing flame is green while hot, colorless when cold. In the reducing flame it is green-gray when hot, and violet blue when cold. The mineral is completely soluble in hot H_2SO_4.

It alters to ilmenite and magnetite, and possibly anatase.

Syntheses.—Crystals have been formed by heating a mixture of TiO_2, $CaCO_3$ and an alkaline carbonate until all the alkali volatilized, and by fusion of TiO_2, $CaCO_3$ and $CaCl_2$.

Occurrence and Localities.—Microscopic crystals of perovskite occur in some igneous rocks, where they are probably separated from the magma producing the rock. It also occurs in chlorite schist and limestone as small crystals embedded in the rocks, and also implanted on the walls of cracks at the Achmaton Mine in the District Slatonst, in the Urals; near the Findelen glacier near Zermatt, Switzerland; in Val Malenco, Italy; at Magnet Cove, Arkansas, in coarse-grained, nepheline syenite; and associated with magnetite in great quantity at Catalão, Goyaz, Brazil.

Ilmenite ($FeTiO_3$)

Ilmenite or menaccanite, is one of a series of isomorphous compounds consisting of the titanates of Mg, Mn and Fe, all of which crystallize in the rhombohedral tetartohedral division of the hexagonal system (trigonal rhombohedral class). The crystallographic constants of ilmenite are, however, so nearly like those of the mineral hematite, which is ditrigonal skalenohedral, that the two compounds often crystallize together, and consequently many specimens of ilmenite when analyzed show notable quantities of Fe_2O_3. These are regarded as solid solutions of Fe_2O_3 in an isomorphous mixture of $FeTiO_3$ and $MgTiO_3$. The axial ratios of the two minerals are:

Ilmenite $a : c = 1 : 1.385$.
Hematite $a : c = 1 : 1.365$.

The composition corresponding to the above formula is Ti = 31.6 per cent, Fe″ = 36.8 per cent and O = 31.6 per cent, but the mineral nearly always contains some Mg and ferric iron (Fe_2O_3). An analysis of ilmenite separated from a peridotite in Kentucky gave:

TiO_2	FeO	MgO	Fe_2O_3	Al_2O_3	SiO_2	Other	Total
49.32	27.81	8.68	9.13	2.84	.76	1.56	100.10

Ilmenite is rarely found in crystals. It is usually in large homogeneous masses, in granular aggregates, in thin plates and in sand grains. The crystals have a tabular or rhombohedral habit and resemble very closely those of hematite. The predominant forms are $R(10\bar{1}1)$, $oR(0001)$ $\frac{\frac{4}{3}P2}{2}l(4\bar{2}\bar{2}3)$, $-2R(02\bar{2}1)$ and $-\frac{1}{2}R(01\bar{1}2)$ (Fig. 259). The angle $10\bar{1}1 \wedge \bar{1}101 = 94° 29'$. Simple crystals, bounded by $oR(0001)$, $R(10\bar{1}1)$ and $-R(01\bar{1}1)$ are also common.

The mineral is black and opaque, and its streak is black to brownish

red. Its cleavage is parallel to oR(0001), and its fracture conchoidal. It has a submetallic luster, a hardness of 5 to 6, and a specific gravity of 4.5–5. It is slightly magnetic, and is a good conductor of electricity.

Before the blowpipe ilmenite is nearly infusible. It gives the reactions for iron with beads. When the microcosmic salt bead, which is brownish red in the reducing flame, is treated with tin on charcoal it changes to a violet-red color. The pulverized mineral is slowly dissolved in hot HCl to a yellow solution. If this is filtered and boiled with the addition of tin it changes to blue, indicating titanium.

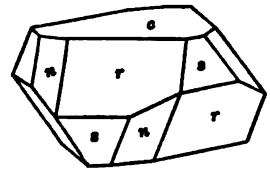


FIG. 259.—Ilmenite Crystal with R, $10\bar{1}1$ (*r*); oP, 0001 (*c*); $\frac{\frac{1}{2}P2}{2}l$, $4\bar{2}\bar{2}3$ (*n*) and $-2R$, $02\bar{2}1$ (*s*).

Ilmenite can be distinguished from *hematite* by its streak, from *magnetite* by its lack of strong magnetism and from most other heavy black minerals by its reaction for titanium.

Upon weathering ilmenite alters to sphene and limonite.

Synthesis.—Crystals have been obtained by melting together TiO_2 and $FeCl_2$.

Occurrence.—The mineral occurs as a constituent of many igneous rocks, and of the crystalline schists produced from them by metamorphism, especially of gabbros and diorites and their derived schists, where it has crystallized from the magma forming the original rocks. It occurs also in veins cutting these rocks and also as great masses near their contacts with other rocks. In a few places it forms the main component of sand.

Localities.—The mineral is found at many places where gabbros and diorites abound. Its principal occurrences in Europe are in the Ilmen Mountains, Ural; at Menaccan, Cornwall, England, and at Kragerö, Arendal and Snarum in Norway. In North America it is found as crystals in pegmatites at several points in Orange County, New York, at Litchfield, Connecticut; at Bay St. Paul, Quebec; and in large masses in the Adirondacks, New York, and in northeastern Minnesota.

Uses.—Because of its abundance, many attempts have been made to utilize ilmenite as an ore of iron, but on account of the large quantity of titanium in it, no satisfactory means of smelting it on a commercial scale have been successful, and consequently the mineral has little value at present. With improvements in the processes of electric smelting, however, it may before long become an economically important source of iron.

Titanite ($CaSiTiO_5$)

Titanite, or sphene, usually occurs as crystals, but in some places in granular and compact masses. Although the formula for the mineral is simple, as given above, requiring as it does 28.6 per cent CaO, 40.8 per cent TiO_2, and 30.6 per cent SiO_2, many specimens show also the presence of Fe_2O_3, Al_2O_3, and in many cases considerable quantities of Y_2O_3.

Analyses of three specimens from different localities yielded:

	SiO_2	TiO_2	CaO	Fe_2O_3	Al_2O_3	Y_2O_3	MnO	Total
Zillerthal...	32.29	41.58	26.61	1.07	....	....	....	101.55
Arendal....	30.00	29.01	18.92	6.35	6.09	9.62	*	100.98
St. Marcel..	30.40	42.00	24.30	tr.	....	....	3.80	100.50

* Besides .94% MgO. .60% K_2O and .54% loss.

The crystals are monoclinic (prismatic class), with $a : b : c = .7547 : 1 : .8543$ and $\beta = 119° 43'$. Their habit varies widely. Some are

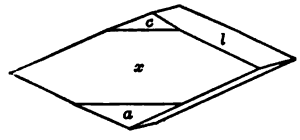


FIG. 260.

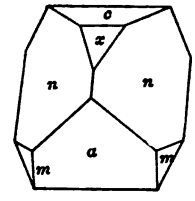


FIG. 261.

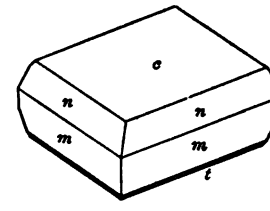


FIG. 262.

FIG. 260.—Titanite Crystal with $\infty P\bar{\infty}$, 100 (*a*); $-\frac{1}{2}P\bar{\infty}$, 102 (*x*); oP, 001 (*c*) and $\frac{1}{2}P$, $\bar{1}12$ (*l*).

FIG. 261.—Titanite Crystal with *a*, *x* and *c* as in Fig. 260. Also $-P$, 111 (*n*) and ∞P, 110 (*m*).

FIG. 262.—Titanite Crystal with *m*, *n* and *c* as in Fig. 261. Also $+P$, $\bar{1}11$ (*t*).

double-wedge-like, others are envelope-shaped, others prismatic, and others tabular. On the wedge-shaped crystals $\frac{1}{2}P(\bar{1}12)$ and $-\frac{1}{2}P\bar{\infty}$ (102) predominate (Fig. 260). On the envelope-shaped ones $\infty P\bar{\infty}$ (100), $-P(111)$ and oP(001) are most prominent (Fig. 261), and on the tabular ones oP(001) is the largest face (Fig. 262). The prismatic crystals are often more complicated. In all about 75 forms have been identified. Both contact and penetration twins are common, with $\infty P\bar{\infty}$ (100)

the twinning plane. The cleavage is distinct parallel to $\infty P(110)$, and there is often, in addition, a very perfect parting parallel to $-2P(221)$, which is due to polysynthetic twinning. The planes $\infty P\bar{\infty}(100)$ and $\frac{1}{2}P(\bar{1}12)$ are often striated parallel to their intersection with $\infty P(110)$. The angle $110 \wedge 1\bar{1}0 = 66° 29'$.

The mineral is brown, gray, yellow, green, black, rose or white. Its streak is white or pink, its luster is vitreous or resinous and it is transparent, translucent or opaque. Its hardness is 5–5.5 and gravity 3.5. It is pleochroic in yellow, pinkish and nearly colorless tints. Its refractive indices vary widely with the composition. In a specimen from St. Gothard, the indices for yellow light are: $\alpha = 1.874$, $\beta = 1.8940$, $\gamma = 2.0093$. The principal recognized varieties are:

Titanite, opaque or translucent with black or brown colors.

Sphene, translucent, light-colored, brown or yellow.

Titanomorphite, white, granular alteration product of rutile or ilmenite.

Greenovite, rose-red, translucent variety containing manganese.

When heated before the blowpipe the mineral fuses to a dark glass, its fusing point being 1210°–1230°. With beads some varieties exhibit the reaction for manganese and all show the colors characteristic of titanium. All varieties are sufficiently soluble in HCl to give the violet-colored solution when treated with tin, and all are completely decomposed by H_2SO_4.

Sphene is distinguished from *staurolite* and *garnet* by its crystallization and softness; from *sphalerite* by its greater hardness; from other similarly colored minerals by the reaction for titanium.

Upon decomposition it yields calcite, magnetite, rutile and other oxides of titanium and ilmenite.

Synthesis.—Crystals of titanite have been made by fusing SiO_2 and TiO_2 with an excess of $CaCl_2$.

Occurrence.—Sphene is a widely spread constituent of igneous rocks where it has probably formed directly by crystallization from a molten magma, and is in many schists and limestones that have been metamorphosed. In the latter cases it is of metasomatic origin. It occurs also as implanted crystals on the walls of cracks and cavities in acid granular rocks, under which conditions it is pneumatolytic. Further, it is a common decomposition product of ilmenite and rutile.

Localities.—The mineral occurs so widely spread that even its principal localities are too numerous to mention here. Particularly fine crystals are found at Ala and St. Marcel, in Piedmont; at various points

in the Zillerthal, Tyrol; at Zoptau, in Moravia; near Tavistock and Tremadoc, in Wales; at Sandford, Maine; at various points in Lewis, St. Lawrence and Orange Counties, New York, principally in limestones; at Franklin Furnace, New Jersey, also in limestone; in Iredell, Buncombe and Alexander Counties, North Carolina, and near Eganville, Renfrew County, Ontario.

PART III

DETERMINATIVE MINERALOGY

CHAPTER XXII

GENERAL PRINCIPLES OF BLOWPIPE ANALYSIS

Determinative Mineralogy.—Minerals are identified by means of their chemical and physical properties. A mineral specimen may be analyzed by the ordinary methods of chemistry. This procedure will reveal its empirical composition but it will not distinguish between dimorphs. For this other means must be relied upon, and of these the most convenient are those based upon physical properties.

Since chemical analysis in the ordinary way is a long and tedious process, requiring bulky reagents and laboratory apparatus, it is not applicable in the field or when rapid determinations are desired. Consequently, chemical analyses are employed only when other methods of determining a mineral are inadequate or when the accurate composition of the specimen is desired.

The usual methods of determining minerals employed by mineralogists are based on their physical properties and upon blowpipe tests; the latter being utilized to differentiate substances with nearly similar physical properties.

Blowpipe Analysis.—By means of the high temperatures that may be secured with the aid of the blowpipe, many chemical reactions may be made to take place which are impossible at ordinary temperatures. The reagents used are few and generally in the solid form, and consequently may be made to occupy little space. Many of the reactions are delicate and characteristic of the different elements and most of them may be made rapidly and with small quantities of material. The results are qualitative only, but when combined with the study of the physical properties of the substance tested, they are usually sufficiently definite to enable one to recognize its nature. In a few instances liquid

reagents must be employed to give decisive results, but they are few and easily obtained.

The Blowpipe.—The blowpipe (Fig. 263), in its simplest form, is a tube with a small outlet through which a current of air may be directed through a flame upon a small particle of substance. A practical instrument consists of a mouthpiece, a tube, an air-chamber to catch moisture, a side tube and a tip pierced by a small hole. The tip is placed in the flame of a Bunsen burner, an alcohol lamp or some other source of flame, and a current of air is blown through it by placing the mouthpiece to the lips, breathing full, and allowing the contraction of the cheeks to force the air from the mouth. Other forms of blowpipe are advocated for special purposes. Frequently the side tube is curved in such a way that the air passing through it is heated before it issues from the tip and a hotter flame is produced than is possible with the simpler instrument.

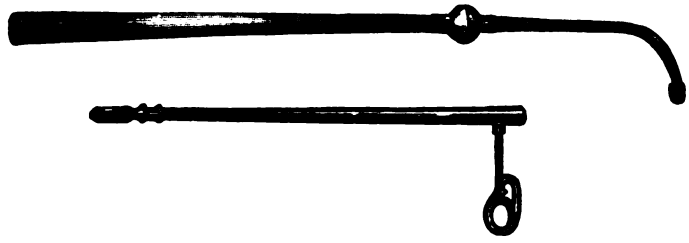


FIG. 263.—Simple Blowpipes.

FIG. 264.—Bellows for Use with Blowpipe. If intended to be worked by hand the apparatus is lighter and of a little different shape.

Since it is often desirable to have the hands free to manipulate the assay, the blowpipe is sometimes fastened to a stand and a blower is attached to it. This not only releases the hand that is employed in holding the simpler blowpipe but it also relieves the cheeks from the somewhat tiresome process of blowing. The blower employed is usually a rubber bag (Fig. 264), protected by a net and provided with a suitable valve to prevent a return current when the pressure that forces the air from the reservoir is removed. The

pressure required to force the air from the reservoir is applied by the foot.

Source of Heat.—The best source of flame for general use with the blowpipe is the Bunsen burner supplied by ordinary gas, and furnished with a tip which is flattened at the upper end and cut off obliquely. The blowpipe is supported on the upper end of this tip and pointed downward parallel with it. Thus, the flame is blown down upon the assay.

Since, however, illuminating gas often contains noticeable traces of sulphur, for the detection of this substance it is often advisable to substitute an alcohol lamp for the gas burner. With the alcohol should be mixed a little turpentine in the proportion of one part of the latter to twelve of the former to increase the reducing power of the flame.

Supports.—The principal supports used to hold the material under investigation—the assay—are charcoal, platinum, and glass. Sheets of aluminium, plaster slabs and unglazed porcelain are also sometimes employed, but for most purposes the first three are entirely adequate.

Charcoal.—Charcoal is used in reduction tests and in the study of sublimates. It should have a flat surface and should be well burned.

Platinum.—Platinum is used principally in the form of wire and foil. The wire should be of about the thickness of coarse horsehair (.4 mm.), and should be fused into a 3-inch long glass tube to serve as a handle. It is employed mainly in the production of colored glasses or beads. The foil should be thin. When about to be used, it should be bent into a shallow cup in which mixtures may be fused.

Glass.—Glass is used in the form of tubes. These should be of a hard glass about 90 mm. long and 6 mm. inside diameter. When closed at one end, they serve to hold substances which are to be heated to a high temperature in the study of their volatile constituents. Tubes open at both ends are employed to study the effect of roasting the assay in a current of air.

Other Apparatus.—Other pieces of apparatus desirable for satisfactory blowpipe work are: A magnet, a magnifier, a pair of forceps, a small hammer, an anvil, a pair of cutting pincers, a piece of blue glass or a screen composed of strips of celluloid colored different shades of blue, or a hollow glass prism filled with indigo solution.

Reagents.—Since blowpipe tests are made on minute quantities of material, it is necessary that all reagents used be as pure as possible. Those most frequently employed are: *Borax*, $Na_2B_4O_7 \cdot 10H_2O$; *microcosmic salt*, or *salt of phosphorus*, $NH_4NaHPO_4 \cdot 4H_2O$; *fused sodium carbonate*, Na_2CO_3; *acid potassium sulphate*, $HKSO_4$; *niter*, KNO_3; *cobalt*

nitrate, $Co(NO_3)_2 \cdot 6H_2O$, in solution; *copper oxide*, CuO; *magnesium ribbon*, Mg; *granulated zinc*, Zn; *sulphuric acid*, H_2SO_4; *hydrochloric acid*, HCl, and *blue litmus* and *turmeric papers*. Other reagents are employed in special tests, but those mentioned above are used generally.

The Blowpipe Flame.—The blowpipe flame is used not only for producing a high temperature, but also to produce oxidizing and reducing effects. The oxidizing flame aids in adding oxygen to the substance heated and the reducing flame abstracts it.

A luminous flame, such as is produced by a candle or a Bunsen burner, with the airholes at the foot of the tube closed, consists of (*c*) an inner, non-luminous cone (Fig. 265) containing unignited gas, (*b*) a luminous envelope surrounding this, in which there is partial combustion of the gas passing out from the nonluminous cone, and an outer purplish mantle.

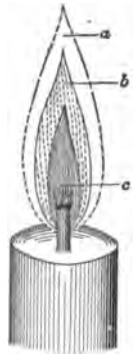


FIG. 265.—Candle Flame, Showing Three Mantles.

Because protected from the air by the outer mantle, the gas in the luminous inner cone is not entirely consumed. The available oxygen combines with the easily combustible hydrogen, while the carbon of the gas is separated in extremely fine particles. These are at a high temperature and are, therefore, incandescent. In this condition, carbon is an active reducing agent, combining with oxygen readily, abstracting it for this purpose from any oxygen-bearing compound with which it is brought in contact. Consequently this portion of the flame exerts a *reducing action* upon anything within its sphere. In the outer mantle, there is an abundance of oxygen. This combines with the carbon particles as they pass out from the luminous envelope, forming, at first, carbon monoxide, CO. This unites with more oxygen forming carbon dioxide, CO_2, and giving a blue flame. Since the temperature in this portion of the flame is very high and there is an abundance of oxygen present, substances subjected to its action are *oxidized*.

The use of the blowpipe accentuates the effects of the different portions of the flame and serves to direct it upon the particle to be tested.

To produce the reducing flame (R.F.), the blowpipe jet is placed at the edge of the burner flame near its base, and a gentle current of air is blown (Fig. 266). This deflects the flame without mixing too much oxygen with it—and it remains luminous. Its most energetic part is near the end of the luminous cone (*a*).

The oxidizing flame (O.F.) is produced by passing the tip of the blow-

pipe into the flame a short distance (Fig. 267) and blowing strongly, but steadily. A sharp-pointed, nonluminous flame results, with an inner blue cone. The most effective oxidizing area is just beyond the tip of the inner blue cone.

Before attempting to use the blowpipe for producing oxidizing and reducing effects, the two flames should be practiced with until they can be manipulated with certainty. The reducing flame is the most difficult to use successfully. It must be maintained unchanged for some time and the assay must be completely enveloped in it to secure satisfactory results. Otherwise, oxidation may ensue. In order to test one's ability

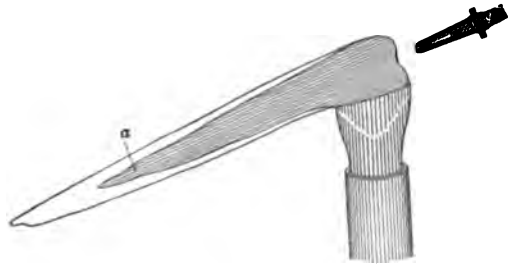


FIG. 266.—Reducing Flame.

FIG. 267.—Oxidizing Flame.

to reduce with the blowpipe flame, a little borax should be melted in a small loop made at the end of a platinum wire. It will form a colorless glass. Into this should be introduced a tiny grain of some manganese compound. If the borax with the added manganese is heated in the oxidizing flame, an amethyst-colored glass will result. This, if heated in the reducing flame, will again become colorless, but the color will return if the assay is touched by the oxidizing flame. When the color can be made to disappear and reappear at will, the proper amount of skill for the manipulation of the flames will have been attained.

Use of the Closed Tube.—The closed glass tube is used to discover whether a substance contains water or not, to detect its volatile con-

stituents, and to discover the nature of its decomposition products. It is also employed in the observation of certain other characteristic changes in a substance produced by heating it to a high temperature.

The material to be tested is powdered and slid into the tube with the help of a little, narrow paper trough, which is long enough to reach nearly to its bottom. The tube is then tapped to settle the material and the end containing the assay is heated, at first gently, later more vigorously, even to redness, either in the burner flame or in the flame produced by the blowpipe.

Water is indicated by the condensation of little drops on the upper, cooler portion of the tube. If the water, when tested with litmus paper, reacts acid, a volatile acid (H_2SO_4, HCl, HNO_3 or HF) is indicated. If it reacts alkaline, ammonia has been evolved.

Gases.—The character of the gases evolved is best recognized by their color and odor.

(*a*) *Hydrogen sulphide* (H_2S) is recognized by its odor. It indicates a sulphide containing water.

(*b*) *Nitrogen peroxide* (N_2O_4) is recognized by its reddish brown fumes and its characteristic odor. It indicates a nitrate or a nitrite. In the case of HNO_3, the reaction is $2HNO_3 = O + H_2O + N_2O_4$.

(*c*) *Hydrofluoric acid* (HF) attacks the glass of the tube and etches it. Its presence in the assay indicates a fluoride.

Sublimates or coatings may be deposited in the cooler portion of the tube.

(*a*) If *white*, they may indicate ammonia salts, antimony trioxide, arsenic trioxide or tellurium dioxide.

(*b*) If *gray* or *black*, they indicate arsenic, mercury or tellurium.

(*c*) If *black, while hot*, and *reddish brown, when cold*, antimony sulphide; and if *reddish brown, while hot*, and *reddish yellow, when cold*, arsenic sulphide.

Changes of Color are very characteristic for certain substances, the following being of greatest importance:

(*a*) From *white* to *yellow* and to *white* again on cooling: zinc oxide.

(*b*) From *white* to *brownish red* and back to *yellow:* lead oxide.

(*c*) From *white* to *orange-yellow* and back to *pale yellow* when again cold: bismuth oxide.

(*d*) From *red* to *black* and *red* again when cold: mercuric and ferric oxides. The mercury oxide is volatile.

Use of the Open Tube.—The open tube is used when it is desired to treat the assay with a current of hot oxygen. It is charged in the same manner as the closed tube, the assay being placed about 12 mm. from

the end. The tube is then held in the forceps over the flame, care being taken to incline it slightly for the purpose of producing an upward current of hot air. By this means, the following substances are easily detected:

Sulphur is detected by the choking odor of SO_2.

Arsenic yields a white volatile sublimate, which disappears upon heating.

Antimony gives white fumes which may partly condense on the cooler portion of the tube as a white sublimate and partly escape from its end. The sublimate is only slightly volatile.

Mercury yields globules of mercury.

Tellurium yields a white sublimate, which, when heated, fuses to colorless drops.

Selenium gives a sublimate which is white or steel-gray near the assay (SeO_2) and red at a greater distance (SeO_2 and Se). The odor of the volatile metal is exceedingly disagreeable. If the tube is allowed to discharge through the flame, it will produce a blue color.

The Use of the Charcoal.—A shallow depression is made near one end of a piece of charcoal, the powdered assay placed in this, and the

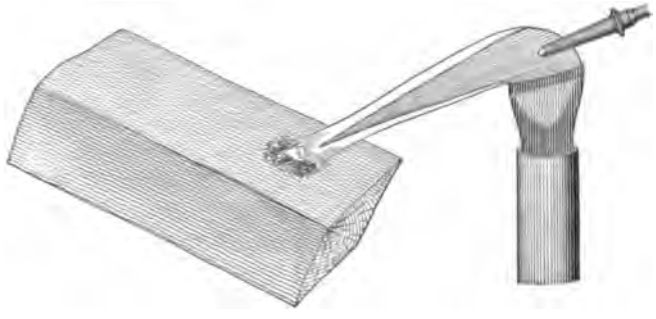


FIG. 268.—Proper position of charcoal.

blowpipe flame played upon it, while the charcoal is held in a tilted position by the left hand (Fig. 268). If the assay decrepitates when heated, it should be moistened with a drop of water. The principal phenomena to be noted are: Volatilization, fusibility, decrepitation, deflagration, odor, reduction and the production of sublimates.

Volatilization.—The substance vaporizes and disappears.

Fusibility.—The substance melts entirely, or partially, in the different parts of the flame, some substances fusing easily and others only with great difficulty.

Decrepitation.—The substance flies to pieces when heat is applied, indicating decomposition or the presence of water, or included gases.

Deflagration.—The substance suddenly burns with little explosions characteristic of *nitrates.*

Reduction and Sublimation.—When heated on charcoal with the R.F., some substances may easily be *reduced* to the metallic state, others are reduced with difficulty. Thus, $2PbO+C=Pb_2+CO_2$. Reduction takes place most readily if the assay is powdered and mixed with about four times its volume of dry sodium carbonate (Na_2CO_3). Thus:

$$2PbS+2Na_2CO_3+C=2Na_2S+Pb_2+3CO_2.$$

In cases of great difficulty, a little potassium cyanide[1] (KCN) or borax ($Na_2B_4O_7 \cdot 10H_2O$) added to the mixture will frequently hasten the result. In any case, the heat must be applied until nearly all the assay sinks into the charcoal.

When sufficiently heated, some substances yield a globule of metal, others are completely volatilized, others yield fumes, produced by the oxidation of portions of the assay, while yet others are partly reduced to a globule of metal and partly volatilized. Thus, during the reduction of PbS, some of the lead may be oxidized according to the reaction:

$$PbS+Na_2CO_3=Na_2S+PbO+CO_2,$$

and a portion of the oxide may settle on the coal. When fumes are produced, they are deposited upon the cooler portions of the charcoal in the form of sublimates which possess characteristic properties.

Gold, silver, and *copper* compounds yield globules of metal without sublimates. The metals are separated for examination by cutting out the charcoal beneath the assay, and crushing the mass with water in a small mortar. Upon pouring off the water, the metal remains as spangles, grains or powder. The silver is recognized by its color and by the fact that its solution in nitric acid yields a white precipitate upon the addition of a drop or two of hydrochloric acid. Copper and gold have nearly the same color, but copper dissolves in nitric acid while gold is insoluble. Addition of an excess of ammonia to the solution of copper gives a characteristic, deep blue color.

Iron, nickel, and *cobalt* give gray infusible powders which are magnetic, but yield no sublimates.

Molybdenum, tungsten, and some of the rarer metals give gray powders that are nonmagnetic and no sublimates.

Antimony yields copious white fumes, forming a volatile white sublimate (Sb_2O_3), which becomes black when touched with the R.F.

[1] Potassium cyanide must always be used with care, as it is a deadly poison, even in minute quantities.

When touched by the tip of the O.F., it will volatilize and color the flame yellowish green. The metallic bead, when dropped upon a sheet of glazed paper, breaks into a number of smaller ones.

Arsenic volatilizes completely and consequently yields no globule of metal. It gives abundant white fumes which form a white sublimate and have a garlic odor. The flame at the same time is colored blue.

Bismuth yields a reddish white, brittle globule and an orange-yellow sublimate which becomes lemon-yellow when cold.

Cadmium gives brown fumes in the O.F. and yields a reddish brown sublimate, while the flame is colored dark green.

Lead yields a gray malleable bead, and incrusts the charcoal with a lemon-yellow sublimate near the assay. The flame at the same time is colored blue. The yellow incrustation is composed of lead oxide.

Molybdenum gives a crystalline incrustation which is yellow when hot and white when cold. When touched by the O.F. it becomes dark blue, and when heated for a longer time dark copper-red. The blue incrustation may be molybdenum molybdate ($MoMoO_4$) and the red one, molybdenum dioxide (MoO_2).

Selenium yields brown fumes, but the sublimate which is near the assay is gray. When heated with the reducing flame, it disappears and the characteristic bad odor is evolved. The flame becomes blue.

Tellurium coats the charcoal with a white sublimate bordered by dark yellow. The coating disappears in the R.F., which acquires a green color.

Tin gives a white globule which is malleable and a yellowish white coating, turning white upon cooling. When moistened with a drop of $Co(NO_3)_2$ solution and heated in the O.F., its color changes to blue-green.

Zinc burns in the O.F. with a bluish white color and evolves thick white fumes which condense as a yellowish sublimate. This becomes white on cooling, and, when moistened with a drop of cobalt nitrate and again heated, it turns grass-green (compare tin).

Other metals also give characteristic reactions on charcoal, but the above are the most important.

Use of the Beads.—The beads are used for the detection of metals that produce characteristic, colored compounds when fused with borax or microcosmic salt or some other reagent. A piece of platinum wire fused into a glass rod serves as a support. The end of the wire is bent into a little loop. This is moistened and plunged into powdered borax, microcosmic salt or other reagent and then heated carefully until the adhering material is fused to a clear glass. New material is added by dipping the loop again and again into the powdered salt and heating until the globules of glass are large enough to fill it completely. A tiny portion of the material to be tested is taken up by heating the bead and pressing it while still soft upon a bit of the powdered assay, which has been placed in a clean watch-glass. The bead containing the substance is then heated with the O.F. and afterward with the R.F., and the phenomena resulting are carefully observed. If the reduction is difficult, a little stannous oxide or chloride will hasten it. If the bead becomes opaque because saturated with the assay, a portion is jerked off while it is hot and it is built up again by the addition of more of the reagent.

In some cases, compounds other than the oxides do not yield the characteristic beads of the metallic oxides. Therefore, it is safer in all cases when testing by the bead reaction, to first roast the substance by gently heating on charcoal with the O.F. to drive off its volatile constituents.

The colors of the most characteristic beads of metallic oxides are tabulated below.

COLORS OF BORAX BEADS

Oxidizing Flame.			Reducing Flame.	
Hot.	Cold.		Hot.	Cold.
Yellow or red	Grass-green	Chromium	Green	Emerald-green
Blue	Blue	Cobalt	Blue	Blue
Green	Blue	Copper	Colorless	Reddish brown, opaque
Colorless	Colorless	Didymium	Rose	Rose
Yellow or red	Colorless or yellow	Iron	Bottle-green	Pale bottle-green
Violet	Reddish violet	Manganese	Colorless	Colorless
Yellow or red	Colorless to opalescent	Molybdenum	Brown	Opaque brown
Violet	Reddish brown	Nickel	Gray	Gray
Colorless	Colorless	Columbium	Colorless or gray	Colorless or gray
Colorless or yellow	Colorless	Titanium	Yellow or brown	Yellow or brown
Colorless or yellow	Colorless	Tungsten	Yellow	Yellow brown
Yellow or red	Colorless or yellow	Uranium	Pale green	Pale green to nearly colorless
Yellow	Green-yellow, or nearly colorless	Vanadium	Brownish green	Emerald-green

COLORS OF MICROCOSMIC SALT BEADS

Oxidizing Flame.			Reducing Flame.	
Hot.	Cold.		Hot.	Cold.
Reddish green	Emerald-green	Chromium	Reddish green	Emerald-green
Blue	Blue	Cobalt	Blue	Blue
Green	Blue	Copper	Dirty green	Green, or opaque red
Colorless	Colorless	Didymium	Colorless	Blue
Yellow or red	Colorless, yellow or brown	Iron	Yellow or red	Nearly colorless
Violet	Violet	Manganese	Colorless	Colorless
Green	Faint yellowish green	Molybdenum	Dirty green	Green
Reddish to brown	Yellowish to reddish	Nickel	Reddish	Yellowish to reddish yellow
Colorless	Colorless	Columbium	Blue or brown	Blue or brown
Skeleton	Skeleton	Silica	Skeleton	Skeleton
Colorless	Colorless	Titanium	Yellow	Violet
Colorless	Colorless	Tungsten	Dirty green-blue	Blue
Yellow	Yellow-green to colorless	Uranium	Dirty green	Bright green
Dark yellow	Light yellow to colorless	Vanadium	Brownish green	Emerald-green

Cobalt is the only metal which produces the same colored bead under all conditions. This is a beautiful blue. Other oxides give blue beads under some one or more conditions, but under other conditions their beads have other colors.

The *cold* bead of chromium oxide is always green and the *oxidized* bead of manganese is always violet.

Flame Coloration.—Many substances impart a distinct color to the nonluminous flame of the burner or the blowpipe. Frequently, these colors are best seen after the substance in powdered form has been moistened with hydrochloric acid, as the chlorides are usually more volatile than other compounds. In the case of silicates, it is often advisable to mix the powdered assay with an equal volume of *powdered gypsum*. In testing for flame coloration a very small particle of the substance, or its moistened powder, or of the mixture of the substance and gypsum is held in the flame by the aid of the platinum loop which has been cleaned by dipping into HCl, and heated repeatedly until it no longer colors the flame.

When several different flame-coloring elements are present in the assay, the stronger color may mask the fainter one, and, therefore, some means must be made use of to shut off the brighter color, while allowing the fainter one to persist. This is usually accomplished by viewing the flame through some medium (a screen) that is transparent to the faint rays and opaque to the brighter ones. In other cases, two flames which are really different in color appear of nearly the same tint to the unaided eye. In this case, the screen is again used to cut off certain

rays that are common to the two colors, when the remaining rays may be different enough to be distinguishable. The screens most frequently used for this purpose are pieces of colored glass, which are held close to the eye. Red glass absorbs all but red rays. Blue glass stops certain red and green rays and all the yellow ones. Great difficulty is sometimes experienced in securing glass exhibiting pure colors, so that in most cases it is more convenient to use transparent celluloid films that have been manufactured expressly for the examination of colored flames. These films are given the tints that are most useful for the purpose desired. Care must be taken in using them, however, since celluloid is highly inflammable.

For more accurate work the spectroscope is often employed. The use of this instrument depends upon the fact that each substance, when in the form of gas, emits light composed of one or more rays of definite wave lengths, and the spectroscope separates these so that each may be identified. The most convenient instrument for blowpipe work is the Browning direct vision pocket spectroscope, but since the constituents of all common minerals can be recognized without the aid of the spectroscope there is no need for further reference to it.

The most characteristic colors imparted to the blowpipe flame are:

Red by lithium, strontium, and calcium. Sodium salts obscure the lithium flame and barium salts the strontium and calcium flames.

Yellow by sodium.

Green by most copper compounds, thallium, barium, antimony, phosphoric acid, boric acid, molybdic acid, and nitric acid. The flame of phosphoric acid is bluish green, the flames of boric acid and barium are yellow green, and those of molybdic acid and antimony are very faint. The copper and thallium flames are vivid greens. The nitric acid flame coloration is bronze green and exists as a flash only.

Blue by copper chloride, copper bromide, selenium, arsenic and lead. The arsenic flame is faint. The selenium and the copper chloride flames are brilliant azure-blue.

Violet by potassium, cæsium and rubidium. Sodium and lithium salts obscure the reaction.

Detection of Certain Elements in the Presence of Others.—In many cases, as has been stated, the color imparted to the flame by one substance entirely obscures that given it by another when the two are present in the same compound. Thus, the faint violet color of the potassium flame is obscured by the strong yellow of sodium and the brilliant red of lithium. When this is the case, the light is viewed through the proper screens and the different rays in this manner are

differentiated. Since the flame tests afford the readiest means of detecting the alkalies and alkaline earths, considerable attention has been devoted to means of differentiating their flame colors. Among the methods proposed for this purpose is that based upon the use of blue and green glass screens.

Detection of the Alkalies and the Alkaline Earths.—The potassium flame is reddish violet through blue glass, while the sodium flame is invisible or is blue; hence, the potassium flame is detected in the presence of sodium by viewing the mixed flame through a blue screen. Lithium is also detected in the presence of sodium with the aid of blue glass, since the lithium flame is violet-red when viewed through a blue screen. Since the flame colors of Li and K are so nearly alike when viewed through a blue screen, they cannot easily be distinguished. When viewed through a green screen, however, the Li flame is nearly invisible, while that of K is bluish green. Through the green screen the Na flame appears orange.

If search is to be made for the alkaline earths, the assay is repeatedly moistened with sulphuric acid and placed in the hottest portion of the flame. After the alkalies are driven off, the flame will become yellowish green, if barium is present; through green glass it will appear bluish green. The assay is then repeatedly moistened with pure hydrochloric acid and again brought, while still moist, into the hottest portion of the flame. A red coloration, appearing after the yellowish green barium flame has disappeared, indicates calcium or strontium or both. Through green glass the calcium flame appears green and the strontium flame faint yellow for an instant. Through blue glass calcium gives a faint greenish gray and strontium a purple or rose color.

The phenomena exhibited by the alkalies and alkaline earths may be summarized as follows:

	Flame Color	Through Blue Glass	Through Green Glass
Potassium	Violet	Reddish violet	Bluish green
Sodium	Yellow	Blue to invisible	Orange-yellow
Lithium	Carmine	Violet-red	Invisible
Barium	Yellow-green		Bluish green
Calcium	Yellow-red	Green-gray	Green
Strontium	Scarlet	Purple	Faint yellow

The detection of the alkalies in silicates is accomplished by fusing the powdered assay on platinum wire with a little pure gypsum. If the alkaline earths are sought for, the assay is fused with sodium carbonate on platinum wire, or better, on a piece of platinum foil. The fused mass

is then extracted with water and the residue treated with hydrochloric acid. Silica will be precipitated, leaving in the solution a mixture of sodium chloride and the chlorides of the alkaline earths. The solution is then tested in the flame with the aid of a clean platinum wire.

The Copper Test.—An almost certain test for copper and for chlorine is afforded by the difference in the color imparted to the flame by copper chloride and most other copper salts. Several substances besides copper give green flames, but in the case of copper alone the color of the flame is changed to sky blue by touching the assay with HCl, or a chloride.

Special Tests.—A few tests with special reagents are so characteristic for certain elements that they are specific:

Tests with Na_2CO_3.—(1) When a powdered substance containing S is fused with four times its volume of dry Na_2CO_3 and heated intensely for some time on charcoal, the residue, when placed on a silver coin and moistened with water or hydrochloric acid, will yield a black or brown stain. This reaction is due to the production of $Na_2S(BaSO_4+Na_2CO_3+C_2=Na_2S+BaCO_3+2CO_2)$, which is soluble. The solution containing the sulphide reacts with the silver, producing insoluble Ag_2S, which is brown or black. Thus: $Na_2S+Ag_2+H_2O+O=Ag_2S+2NaOH$. Sulphides and sulphates are distinguished by roasting the compound on charcoal without Na_2CO_3. Sulphides yield the sulphur-dioxide odor.

(2) *Manganese* and *chromium* compounds, fused with Na_2CO_3 (especially when a little niter is added), yield colored masses—the manganese compound a bright green mass (Na_2MnO_4) and the chromium compounds a bright yellow mass (Na_2CrO_4). In the case of the manganate, the reaction may be

$$MnO_2+Na_2CO_3+O=Na_2MnO_4+CO_2.$$

(3) Sodium carbonate may also be employed for *decomposing silicates* and detecting silicic acids. If a silicate is fused with 4 or 5 times its volume of Na_2CO_3 on charcoal, it will break up, the silica combining with soda to form sodium silicate, thus:

$$(ZnOH)_2SiO_3+2Na_2CO_3=2ZnO+Na_4SiO_4+2CO_2+H_2O.$$

Upon treatment with acid, H_4SiO_4 is produced ($Na_4SiO_4+4HCl=4NaCl+H_4SiO_4$). This appears as a gelatinous precipitate in the solution; but upon evaporating to dryness, moistening with strong acid, and again evaporating to dryness, the H_4SiO_4 is broken down into $2H_2O$ and SiO_2, the latter of which is insoluble, and can be filtered off, leaving the bases in the filtrate.

Tests with the Cobalt Solution.—Certain metallic oxides, when

moistened with a few drops of a solution of crystallized cobalt nitrate dissolved in ten parts of water, and heated, yield distinctive colors that may often serve as aids in their detection. The assay is powdered, moistened with a drop of the cobalt solution, and placed on charcoal and heated intensely. Compounds containing *alumina* yield a mass of a *blue* color, without luster. A few other substances may also give blue masses, but the materials are fused and, consequently, show a glassy luster. *Magnesium* compounds give a *pink* color.

In testing for other substances, it is necessary first to obtain their oxides. This is done by roasting on charcoal until a distinct sublimate is produced. This sublimate is moistened with a drop of the solution and heated gently by the O.F. Under these conditions, the white *zinc sublimate* (ZnO) changes to a bright *yellowish green* and *tin oxide* (SnO_2) to a *bluish green.*

Tests with Acid Potassium Sulphate.—Hydrogen potassium sulphate ($HKSO_4$) when fused with a powdered substance in a closed tube, may cause the evolution of gases. For example:

$$2HKSO_4+CaF_2=K_2SO_4+CaSO_4+2HF,$$

which in many cases may easily be recognized.

Nitrites and *nitrates* yield reddish brown fumes (N_2O_4) with the characteristic odor of nitrogen peroxide.

Chlorates yield a yellowish green explosive gas (ClO_2).

Iodides yield a violet gas, which colors blue a paper soaked in starch paste, when a little MnO_2 is added to the $HKSO_4$.

Bromides yield a reddish brown gas (Br), turning starch paste yellow, when MnO_2 is mixed with the $HKSO_4$.

Chlorides yield hydrochloric acid (HCl), recognized by its odor and the voluminous white fumes it forms with ammonia.

Sulphides yield hydrogen sulphide (H_2S) with its characteristic odor. This gas blackens paper moistened with lead acetate.

Fluorides yield hydrofluoric acid (HF) gas, which has a pungent odor and etches glass. The etching is due to the reaction between the SiO_2 of the glass and the HF. Thus, $SiO_2+4HF=SiF_4+2H_2O$. The SiF_4 is volatile and is driven up the tube, leaving tiny pits from which the SiO_2 was taken. This reaction is best seen by heating the assay with four times its volume of the reagent and then cleaning and drying the tube.

The reaction is more delicate if the finely powdered assay is mixed with microcosmic salt and heated in an open tube. When the salt is heated, it breaks up, yielding $NaPO_3$ (thus: $HNa(NH_4)PO_4\cdot 4H_2O=NaPO_3+NH_3+5H_2O$) which reacts with the fluoride as follows:

$$CaF_2+NaPO_3+H_2O=CaNaPO_4+2HF.$$

By Reduction with Metallic Zinc and Hydrochloric Acid certain metallic salts yield colored solutions which are characteristic. The substance to be tested (if not soluble in HCl) is powdered and mixed thoroughly with sodium carbonate and niter, and the mass is slightly moistened and placed in a little spiral at the end of a fine platinum wire. After fusion, it is dissolved in a little water, a few drops of hydrochloric acid are added and a strip of zinc or tin, or a few grains of the metal, are then placed in the solution. The hydrogen, evolved by the contact of the metal and the acid, reduces the oxides and the solution becomes colored. The most important elements detectable by this method are:

Molybdenum, which gives a blue, then green, and finally a blackish brown solution.

Tungsten, a blue, then brown or copper-red solution.

Vanadium, a blue, green or violet solution.

Columbium, a blue solution which loses its color on addition of water.

Chromium, a green solution.

Titanium, a violet solution.

In the case of titanium the reactions are:

$$TiO_2 + 2Na_2CO_3 = Na_4TiO_4 + 2CO_2;$$
$$Na_4TiO_4 + 8HCl = TiCl_4 + 4NaCl + 4H_2O;$$
$$TiCl_4 + H = TiCl_3 + HCl.$$

The $TiCl_3$ produces the violet solution.

Magnesium ribbon is generally employed as an aid in the detection of phosphorus. The powdered assay is placed in the bottom of a closed glass tube with a piece of magnesium ribbon about 5 mm. long, so that the powder is in close contact with the metal. This is then heated intensely until partial fusion ensues. The completion of the reaction is known by the formation of a brown or black glass, which is the phosphide of magnesium. Upon crushing the tube and moistening its contents with water the characteristic odor of phosphine is perceived (the odor of wet phosphorus matches).

Hydrochloric acid furnishes the readiest test for carbonates. If the powdered substance is heated gently with dilute acid in a test tube, a brisk effervescence will result if it contains the carbonic acid radical. Sometimes the effervescence can be detected by holding the mouth of the test tube to the ear, even when the escape of gas cannot be seen. The gas (CO_2) is colorless, and when allowed to bubble through lime water will cause turbidity.

CHAPTER XXIII

CHARACTERISTIC REACTIONS OF THE MORE IMPORTANT ELEMENTS AND ACID RADICALS

Aluminium (p. 481).—Fusible minerals cannot be satisfactorily tested for Al by the method using $Co(NO_3)_2$, since cobalt imparts a blue color to all glasses.

Since zinc silicates yield the same color reaction with $Co(NO_3)_2$ as do infusible aluminium compounds, the presence of aluminium in silicates cannot be assured unless the absence of zinc is proven.

Antimony (pp. 472, 473, 474, 478).—In the presence of lead or bismuth, the assay is heated on charcoal with fused boric acid, which dissolves the lead and bismuth oxides, while the antimony oxide coats the charcoal.

When antimony and lead are present in the same compound, the antimony oxide forms a white incrustation surrounding a dark orange-yellow incrustation of lead antimonate.

Arsenic (pp. 472, 473, 475, 478).—Arsenic in arsenates and arsenites may usually be detected by heating the powdered assay with six times its volume of a mixture of equal parts of Na_2CO_3 and KCN (or powdered charcoal) in a dry closed glass tube, when an arsenic mirror will form on the cold part of the tube. This may be further tested by breaking off the end of the tube and heating the mirror in the burner flame. The escaping fumes will have the characteristic garlic odor. If allowed to pass through the flame, they will tinge it violet.

If there is doubt as to whether a white sublimate on charcoal contains arsenic, or if it is desired to test for arsenic in the presence of antimony, a little of the coating which is farthest away from the assay may be scraped from the surface of the charcoal and placed in a narrow glass tube and heated. If arsenic oxide is present in the coating, the arsenic mirror will form on the walls of the cooler part of the tube.

Barium (pp. 478, 479).—Before applying the flame test for barium, silicates should first be fused with four parts of dry Na_2CO_3 and charcoal in a loop of platinum wire, crushed, placed in a test tube, treated with a

few cc. of dilute HNO_3 and evaporated to dryness. After cooling, warm with a very little HCl, then add about 10 cc. of water and filter off the insoluble silica. To the filtrate add a few drops of H_2SO_4, collect the precipitate on a small filter, and test with the flame (see also under *Calcium*).

Bismuth (pp. 472, 475).—A very characteristic test is the following: The powdered substance is mixed with twice its volume of a mixture composed of equal parts of KI and flowers of sulphur, and heated in the R.F. on charcoal. If Bi is present, a brick-red iodide of bismuth will form a coating at some little distance from the assay. This test serves to distinguish between Pb and Bi, both of which yield yellow oxide coatings when tested on charcoal.

Boron (p. 478).—To obtain the green flame in the case of most compounds containing boron, it is usually sufficient to moisten the fine powder with a drop of strong sulphuric acid and introduce a small quantity into the flame on a platinum wire. The flame will be colored green, but only for a moment. More resistant compounds, like the silicates, must be fused with a flux composed of one part of powdered fluorspar and four parts of $KHSO_4$ before the green coloration can be obtained. The HF generated decomposes the silicate and sets free the boron.

In the presence of copper compounds or phosphates, which also give green flames, the finely powdered assay is moistened on platinum foil with sulphuric acid. The excess of acid is then removed by heating, and the powder mixed into a paste with glycerine and a little sodium carbonate. When heated in the flame, the sodium will mask the green color due to the copper and phosphorus, but not that produced by boron.

If boron compounds are fused with Na_2CO_3 and then treated with dilute HCl, a drop of the resulting solution will cause turmeric paper to turn reddish brown after being dried at 100°. If moistened with ammonia, the color changes to black.

Bromine (pp. 478, 481).—Solutions of bromides in water or HNO_3 (after fusion with Na_2CO_3 if insoluble otherwise) will yield with a drop or two of silver nitrate solution a yellowish precipitate of AgBr, which is soluble in ammonia. If this precipitate is mixed with Bi_2S_3 and heated in a closed tube, a yellowish sublimate of $BiBr_3$ will result. (Compare *Chlorine* and *Iodine*.)

Cadmium (pp. 475, 478).—When present with Pb or Zn, it is often difficult to recognize the cadmium coating on charcoal. In this case, the

coating may be scraped from the coal and heated very gently in the closed tube. A yellow sublimate of cadmium oxide will form just above the assay. On further heating, this will be masked by the zinc and lead oxides.

Calcium (pp. 478, 479).—Calcium in silicates and other insoluble compounds may be detected by the same method as that used for the detection of barium. The precipitate of $CaSO_4$, however, is dissolved when heated with a large volume of water.

Carbonates.—See p. 482.

Chlorine (pp. 480, 481).—Chloride solutions, when treated with $AgNO_3$, yield a white precipitate of AgCl, soluble in ammonia. When exposed to the light, it darkens. If mixed with Bi_2S_3 and heated in a closed tube, a white sublimate of $BiCl_3$ is formed. (Compare *Bromine* and *Iodine.*)

Chromium (pp. 476, 477, 480, 482).—In the presence of large quantities of Fe, Cu, etc., the powdered assay (if not a silicate) is mixed with double its volume of equal parts of Na_2CO_3 and KNO_3 and fused on a platinum spiral in the O.F., when an alkaline chromate will be formed. This, dissolved in water and boiled with an excess of acetic acid yields a solution which gives a yellow precipitate of $PbCrO_4$ with a few drops of lead acetate.

Silicates containing small quantities of chromium and large quantities of copper and iron should first be fused on charcoal with a mixture of one part of sodium carbonate and a half part of borax. The clear glass thus produced is dissolved in hydrochloric acid and the solution evaporated to dryness. This is then treated with water, filtered, and the filtrate boiled with a few drops of nitric acid to oxidize the iron. By the addition of ammonia, the chromic and other oxides are precipitated. The precipitate is collected on a filter, washed, and treated as above, or tested with the borax bead.

Cobalt (pp. 474, 476, 477).—For the detection of cobalt in the presence of iron or nickel, see under those metals.

Columbium (pp. 476, 477, 482).—When a compound containing columbium is fused with five parts of borax on platinum foil, dissolved in concentrated HCl and diluted with a little water, the solution becomes blue when boiled with granulated tin. The color does not change to brown on continued boiling. It disappears, however, when diluted with water. If titanium is present in the same solution the

color will be first violet, then blue. Tungsten, which gives a blue solution under the same conditions, can be distinguished from columbium by the bead test. If the solution is boiled with zinc, instead of tin, its color changes rapidly from blue to brown.

Or the finely powdered substance may be fused in a test tube or crucible with ten parts $KHSO_4$, and then digested with cold water for a long time. If columbium is present, an insoluble white residue will be left. This, if collected on a filter, washed, and then treated in a test tube with hot concentrated HCl, will yield the blue solution when boiled with granulated tin.

Copper (pp. 474, 476, 477, 478, 480).—A very delicate test for soluble copper compounds is to dissolve them in HCl or HNO_3, dilute with water and add ammonia in excess. A deep purple-blue solution of $CuCl_2 \cdot 6NH_3$ or $Cu(NO_3)_2 \cdot 6NH_3$ will result.

Fluorine (pp. 472, 481).—If the mineral to be tested is a silicate, its powder is mixed with four parts of fused microcosmic salt and this mixture is heated in a closed tube. If fluorine is present, the glass above the assay will be etched by the HF produced. At the same time, a ring of SiO_2 is deposited in the cool portion of the tube in consequence of the reaction.

$$3SiF_4 + 2H_2O = 2H_2SiF_6 + SiO_2.$$

Upon heating, the ring moves up the tube to a cooler portion.

Gold (p. 474).—The metal is best detected by treatment with aqua regia of the metallic bead, produced by fusion with Na_2CO_3 on charcoal. This yields a light yellow solution, which, when taken up on a filter paper and moistened with stannous chloride, gives the "purple of Cassius."

Or, if the mineral is to be tested for free gold, it is powdered and treated with aqua regia and the solution diluted and filtered. The filtrate is evaporated nearly to dryness, diluted with water and a few drops of a solution of ferrous sulphate are added. If gold is present in small quantity only, the solution will be colored bluish or purple. If the gold is present in larger quantity, the metal will be precipitated as a brown powder.

Free gold may also be detected by powdering the substance until all will pass through a fine sieve. Brush the material adhering to the sieve and add to the powder. Then place in a basin containing a little mercury ($\frac{1}{2}$ cc.), and immerse the basin and its contents in water. Shake the basin gently with a rocking motion and gradually allow the rock

powder to escape. The gold will fall to the bottom and amalgamate with the mercury. After the mass has been reduced to a small volume, transfer to a mortar and grind in a gentle stream of water, until nothing but the amalgam is left. Then place in an iron spoon and heat in the open air until all the mercury is driven off; or the amalgam may be placed in a shallow cavity on charcoal and heated with a small blowpipe flame until all the mercury volatilizes. The residual gold may be collected into a globule by placing a little borax or sodium carbonate in the cavity and heating until quiet fusion takes place.

When driving off the mercury from the amalgam extreme care must be taken not to breathe its fumes, since they are poisonous. The operation should not be performed in a closed room.

Iodine (p. 481).—Substances containing iodine, when fused in a glass tube with $KHSO_4$ and MnO_2, yield a vapor which is recognized as that of iodine by its violet color.

In the presence of other halogens, iodine may be detected by mixing the powdered substance with Bi_2S_3 (prepared by fusing together small quantities of bismuth and sulphur) and heating in a closed tube or on charcoal before the blowpipe. If iodine is present, a red sublimate of bismuth iodide is produced. (Compare *Chlorine* and *Bromine*.)

Iron (pp. 472, 474, 476, 477).—To distinguish ferrous and ferric conditions, the assay is added to a borax bead containing copper. If the iron is in the ferric condition, the bead will be bluish green; if in the ferrous condition, it will contain red streaks of cuprous oxide.

In the presence of easily fusible metals like lead, tin, zinc, etc., the substance is heated on charcoal with borax in the R.F. The easily reducible metals do not become oxidized and, consequently, are not absorbed by the glass. The glass is separated from the metallic bead, and is heated on a fresh piece of charcoal in the R.F., when it acquires the characteristic bottle-green color produced by iron, and becomes vitriol-green on addition of tin.

In the presence of cobalt, the blue color of the cobalt bead masks the green of the iron bead. In this case, iron is detected by heating the blue glass on platinum wire in the O.F. sufficiently long to convert all the iron into peroxide. With very little iron present, the bead is green when hot, and blue when cold; with more iron the bead is dark green when hot, and pure green when cold, this latter color resulting from a mixture of the yellow iron and the blue cobalt colors.

Manganese colors the borax bead in the O.F. red. Upon reduction with tin on charcoal, the bead becomes bottle-green. If cobalt also is

present, the bead produced in the O.F. is dark violet. In the R.F. it becomes green when hot and blue when cold.

Lead (pp. 472, 475, 478,).—The coating of lead oxide resembles very closely that of bismuth. The two may be distinguished by the procedure described under bismuth. The iodide of lead is lemon-yellow.

Lithium (pp. 478, 479).—In the case of silicates, before testing for flame coloration, it is advisable to mix the powder of the assay with one part of fluorspar and one and a half parts of $KHSO_4$ and form into a paste with a drop of water. If boron is present, the flame is at first green, then red. The presence of phosphoric acid is shown by the production of a green flame together with the red one. This is especially noticeable after moistening the assay with sulphuric acid.

Magnesium (p. 481).—The $Co(NO_3)_2$ test for magnesium is applicable only to white or colorless minerals and is by no means conclusive. The most satisfactory test is that employed generally in ordinary qualitative analysis, viz., precipitation with the aid of sodium phosphate (Na_3PO_4). The powdered mineral, if insoluble in acids, is fused with Na_2CO_3, powdered, dissolved in a few cc. of dilute HNO_3 and evaporated to dryness. It is then dissolved in 2 or 3 cc. HCl and warmed for a few minutes. There is next added about 10 cc. of water and the solution is boiled and filtered to remove silica. The filtrate is heated to boiling and NH_4OH is added in slight excess to precipitate iron and aluminium. This is now filtered and the filtrate is boiled again, and to it is added some ammonium oxalate ($(NH_4)_2C_2O_4$) to separate calcium. After ten or fifteen minutes, the calcium oxalate is removed by several filtrations until the filtrate is clear. To the filtrate a solution of sodium phosphate and strong ammonia are added. If magnesium is present after standing for some time, a fine white crystalline precipitate of $NH_4MgPO_4 \cdot 6H_2O$ will form.

Manganese (pp. 477, 480).—Manganese compounds soluble in HNO_3 are readily detected by oxidation with persulphates. The procedure is to dissolve in a few cc. of moderately dilute HNO_3 (sp. gr. 1.2), add about one-half its volume of dilute solution of $AgNO_3$ and a few drops of ammonium persulphate (200 gr. $(NH_4)_2S_2O_8$ to one liter of water) and gently heat. The manganese will be oxidized to permanganic acid, which is purple. The reaction is

$$2Mn(NO_3)_2 + 5(NH_4)_2S_2O_8 + 8H_2O$$
$$= 5(NH_4)_2SO_4 + 5H_2SO_4 + 4HNO_3 + 2HMnO_4.$$

Compounds that are insoluble in HNO_3 must first be fused with Na_2CO_3 on charcoal.

Mercury (pp. 472, 473).—In the presence of sulphur, chlorine, iodine and a few acids, the assay is best heated with dry Na_2CO_3 in a closed glass tube. The acid combines with the Na and the Hg sublimes.

Molybdenum (pp. 474, 475, 477, 478, 482).—The white coating of MoO_3 on charcoal, if touched with the R.F., is partly reduced, becoming blue. If heated by the O.F., some of it volatilizes, but some is reduced by the charcoal, forming a copper-red coating.

Small quantities of molybdenum are detected by treating the powdered assay with a little strong sulphuric acid on a platinum foil. After heating until most of the acid is evaporated, and then cooling, the resulting mass becomes blue, particularly after being repeatedly breathed upon, or after being moistened with alcohol and dried by heating.

Nickel (pp. 474, 476, 477).—In the presence of Co, the color of the Ni borax bead is often masked. In such cases, a small portion of the mineral is fused in the R.F. to a globule. A fragment of borax " twice the size of the globule is placed beside it on charcoal and the two are heated by the O.F. The two globules will roll around under the flame in contact, but will remain quite distinct; any cobalt will be oxidized by the O.F. and be absorbed by the borax, which will become blue. If the mineral is placed upon a clean part of the coal and the treatment is continued with fresh portions of borax until all the cobalt has been oxidized and the borax no longer becomes blue, the nickel present will impart its characteristic violet and reddish brown color to the borax." (Phillips.)

Nickel is best detected by treating its solution with dimethyl glyoxime ($(CH_3)_2C_2(NOH)_2$). The assay is dissolved in acid, after fusion with Na_2CO_3, if necessary, and the solution is neutralized with $(NH_4)OH$. Add one-half volume of dimethyl glyoxime solution, made by dissolving one part of the compound in 100 pts. of a 40 per cent. alcohol, and again add a little $(NH_4)OH$ to neutralize. A bright red crystalline precipitate will form if nickel is present, according to the reaction:

$$NiCl_2 + 2(CH_3)_2C_2(NOH)_2$$
$$= (CH_3)_2C_2(NOH)_2 \cdot (CH_3)_2C_2(NO)_2Ni + 2HCl.$$

Nitric Acid (pp. 472, 478, 481).—Nitric acid is best detected by dissolving the assay in dilute (1 : 1) H_2SO_4, cooling and adding to the solution in a test tube a few drops of a strong solution of $FeSO_4$ in water,

holding the tube slanting and allowing the $FeSO_4$ to trickle quietly down its side and form a layer upon the acid solution. If nitrates are present, a brown ring will form at the contact of the two solutions.

Oxygen, in some of the higher oxides, may be detected by the liberation of chlorine when they are treated with HCl. This is particularly the case with the higher oxides of manganese, thus:

$$MnO_2+4HCl=MnCl_2+2H_2O+2Cl.$$

The chlorine is recognized by its color, its odor and its bleaching action.

Phosphoric Acid (pp. 478, 482).—In the test with magnesium ribbon, it is best to fuse the phosphates of Al and the heavy metals with two parts of Na_2CO_3 on charcoal, to remove and grind the fused mass, and then to ignite the powder with magnesium ribbon in a closed glass tube (Brush and Penfield).

If a small crystal of ammonium molybdate $(NH_4)_2MoO_4$ be placed on a phosphate and a little dilute HNO_3 be dropped upon it, the crystal will turn yellow in consequence of the production of ammonium phosphomolybdate $11(MoO_3)\cdot(NH_4)_3PO_4\cdot 6H_2O$. This test is available only for compounds that are soluble in HNO_3.

If the mineral is insoluble in HNO_3, it must first be fused with sodium carbonate on platinum wire. The bead is then dissolved in nitric acid and the solution when cold is added drop by drop to a little of an ammonium molybdate solution and allowed to stand without warming. If the assay contained the phosphoric acid radical, a yellow phosphomolybdate will be formed.

Potassium.—See pp. 478 and 479.

Selenium (pp. 473, 475, 478).—Selenates and selenites must be reduced with sodium carbonate on charcoal before the peculiar odor is evolved.

Silicon (pp. 477, 480).—Small splinters of silicates yield an infusible skeleton of silica when heated in a bead of microcosmic salt. This floats around in the liquid bead as a particle with the shape of the original splinter, or as a transparent flake. In some cases the original splinter remains undecomposed.

Many silicates decompose in strong HNO_4 or HCl with the production of a gelatinous mass of silicic acid. If the solution containing the gelatinous silica is evaporated to dryness, the silica becomes insoluble

and remains as a residue when the mass is warmed with a little strong acid and digested with water.

In case of insoluble silicates it is necessary to fuse with Na_2CO_3 before proceeding with the test. The fusion results in the production of a sodium silicate which is soluble in acids. The gelatinous precipitate will appear only after the acid solution of the fused mass is evaporated.

Silver.—See p. 474.

Sodium.—See pp. 478 and 479.

Strontium (pp. 478, 479).—In the case of insoluble compounds treat as in the test for Ba. If both Ba and Sr are present in the final precipitate, the flame will first be crimson. Upon repeated moistening with HCl and heating, the Sr will gradually disappear and the green color of the Ba flame will be seen.

Sulphur (pp. 472, 473, 480, 481).—If a substance containing sulphur is heated with Na_2CO_3 on charcoal in the R.F. and the fused mass is transferred to a watch glass and moistened with water, the addition of a little dilute solution of ammonium molybdate, to which HCl has been added, will produce a blue color.

Sulphides are distinguished from most sulphates (except those containing water or the OH group) by heating in the O.F. The sulphides yield an odor of SO_2. The sulphates yield no odor. Another means of distinguishing between these two classes of compounds is as follows: The finely powdered substance is fused with caustic potash (KOH) in a platinum spoon, or on a piece of platinum foil. The spoon or foil with its contents is thrown into water containing a strip of silver. If the silver remains quite white, the S is present as sulphate; if the silver becomes black, S is present as sulphide. Substances exercising a reducing action must, of course, not be present.

Tantalum cannot be recognized in the presence of columbium by any simple tests.

Tellurium (pp. 473, 475).—A powdered tellurium compound, heated with Na_2CO_3 and charcoal powder in a closed glass tube and treated when cold with hot water, yields a purple red solution of sodium telluride. This color will disappear if air is blown through the solution.

Tellurides may be detected by gently warming the finely powdered substances with a few cc. of concentrated sulphuric acid. The solution

will become carmine. After cooling, the addition of water will precipitate the tellurium as a blackish gray powder, and the carmine color will disappear.

Thallium.—See p. 478.

Tin (pp. 475, 481).—The reduction of tin compounds is accomplished fairly easily by mixing borax with Na_2CO_3 and treating with the R.F. on charcoal. The metallic tin thus obtained, when heated on charcoal by the O.F., yields a white incrustation which becomes bluish green when moistened with cobalt nitrate and heated (see *Zinc*). Or, if warmed in a test tube with moderately dilute HNO_3, a white powdery metastannic acid (H_2SnO_3) will result.

If to a borax bead colored blue by a copper, a small quantity of tin compound be added and the R.F. be applied, the bead will turn brown.

Titanium (pp. 476, 477, 482).—If iron is present, the bead of microcosmic salt in the O.F. has the iron color, and in the R.F. a blood-red color. When this is fused with tin in the R.F. on charcoal, the color becomes violet.

A very characteristic reaction is obtained as follows: Fuse on charcoal or platinum foil one part of the assay with 6 parts of Na_2CO_3 and a little borax. Then dissolve in a small quantity of concentrated HCl (2–2.5 cc.) and add granulated tin. The hydrogen generated by the tin and HCl will reduce the $TiCl_4$ in the original acid solution to $TiCl_3$ and the solution will assume a violet color, especially after standing several hours.

For an extremely delicate test, fuse the powdered assay with Na_2CO_3 and borax, as in the color test with tin. If the fused mass is dissolved by heating in a test tube with 2 cc. of a mixture of equal parts of H_2SO_4 and water, and, after cooling, is diluted with about 10 cc. of cold water, the addition of a few drops of H_2O_2 to the diluted solution will produce a golden yellow or orange color if titanium is present.

Tungsten (pp. 474, 476, 477, 482).—When present in small quantities, tungsten may be detected by fusing the assay with five or six times its weight of Na_2CO_3, extracting the resulting mass with water, filtering and adding to the filtrate strong hydrochloric acid. White tungstic hydroxide will be precipitated and this precipitate will become pale yellow (WO_3) on boiling. Upon acidification and boiling with a few particles of tin, a blue mixture of oxides results. The blue color *will not*

disappear on the addition of water. (Compare tests for *columbium.*) On long-continued boiling, the color will change to brown (WO_2).

If the tungstate be decomposed by boiling with HCl, it is not necessary to fuse. Simply boil with strong acid until a light yellow precipitate (WO_3) is obtained. Then dilute with an equal quantity of water, add tin and boil, and the clue color will result. This will change to brown on long-continued boiling (WO_2).

Uranium (pp. 476, 477,).—If the uranium is so mixed with other metals that its characteristic bead is obscured, dissolve the assay in HCl (first fusing with Na_2CO_3 or borax, if necessary), then nearly neutralize with ammonia and add a strong solution of Na_2CO_3 until precipitation ceases, then about half as much more and let stand for some time. The excess of Na_2CO_3 will dissolve the compound first precipitated. Filter, acidify the filtrate with HCl and boil until all the CO_2 is expelled. Then add ammonia in excess. If uranium is present, it will be precipitated as a gelatinous light yellow ammonium uranate $(NH_4)_2U_2O_7$. To confirm, filter and test the precipitate in the bead of microcosmic salt.

Vanadium (pp. 476, 477, 482).—Vanadium compounds, first roasted on charcoal and then fused with four parts Na_2CO_3 and two parts potassium nitrate on a platinum spiral, when extracted with hot water, filtered, acidified with acetic acid, and treated with a few drops of lead acetate, yield a pale yellow precipitate of $Pb_3(VO_4)_2$. This may be tested for vanadium in a microcosmic salt bead.

If the solution obtained by extracting the fused mass be filtered and acidified with HCl and well shaken with hydrogen peroxide, it will become reddish brown or garnet color. If to the acidified solution metallic zinc be added, a green blue color will result. This, however, will gradually become violet if the solution is left standing in contact with zinc.

If the substance is soluble in concentrated HCl or H_2SO_4, the solution thus produced will be red-brown. On the addition of water the color will change to green-blue or will disappear. Upon the addition of H_2O_2 the reddish brown color will reappear if the dilution be not too great. If treated with metallic zinc the green blue color will again appear, but will gradually change to violet on continued action of the zinc. If the blue or violet solution is poured off the zinc and a few drops of hydrogen peroxide be added, the characteristic brown color will again result. For a more accurate determination of the presence of vanadium, add NH_4OH in excess to the acid solution and pass

through it H_2S. The solution will become garnet if vanadium is present.

Zinc (pp. 472, 475, 481).—Infusible white or light-colored zinc compounds, when finely powdered and made into a paste with a drop of $Co(NO_3)_2$ solution, and then heated on charcoal by an O.F., assume a green color. But silicates of zinc when treated in this way with a hot flame often form a fusible cobalt silicate which is blue.

In the presence of antimony and tin, it is almost impossible to detect zinc by blowpipe tests, as all three metals exhibit nearly the same blowpipe reactions. However, the zinc sublimate when moistened with $Co(NO_3)_2$ solution and heated in the O.F. becomes grass-green, whereas the tin sublimate, under the same treatment, becomes blue-green.

Zirconium, in the absence of titanium, molybdates and boric acid, may be detected, after fusion of the assay with a little Na_2CO_3, by dissolving the assay in a few drops of strong HCl and diluting with water to four times the volume, and then moistening with this dilute solution a piece of turmeric paper. When the paper is dried gently its color will change to reddish or orange if zirconium is present.

APPENDICES

I. GUIDE TO THE DESCRIPTIONS OF MINERALS

BECAUSE of the great number of minerals known and the difficulty of recognizing them at sight, some means must be employed to aid in their systematic study in order that they may be identified without an inordinate expenditure of time. The most convenient method of arriving at the name of a mineral is by means of a guide, or a set of tables similar in scope to the " keys " used in Botany for determining the names of plants. Many tables have been proposed by mineralogists for this purpose and many different kinds are still in use. Some of these are based on the chemical properties of minerals, and others on their physical properties. Both kinds possess advantages. Those based on chemical properties are more effective in leading to the name of the mineral being studied, but those based on physical properties are more apt to lead to a better knowledge of its most evident characteristics.

The most serious objection to the use of determinative tables lies in the danger that the student will feel, when the name of the mineral is obtained, that the object of his search is at an end, whereas their true aim should be to lead him to such a thorough study of the mineral that there will remain no doubt in his mind as to its real nature.

In the present volume the tables are intended to serve simply as guides to the descriptions of the minerals given in the body of the text. It is here that the distinctions between the different species must be found. In many instances the differentiation between several minerals is dependent upon chemical tests; hence it is desirable to familiarize oneself with the characteristic tests of the various metals and the acid radicals.

The tables in the following pages are divided into two great divisions. The first division includes those minerals that have a metallic luster, and a few which might be confused with these. Minerals possessing a metallic luster are opaque on their thinnest edges. Most of them give a black or dark-colored streak. The second division includes the remaining minerals, i.e., those with a nonmetallic luster. These are transparent in splinters and on their thin edges, and most of them give a

colorless or light-colored streak. The subdivisions are based on color of streak, color in reflected light and hardness. With reference to hardness it is convenient to remember that minerals with a hardness of less than 2.5 will leave a mark on paper; those with a hardness of less than 3.5 can be scratched by a cent; those with a hardness of less than 6 can be scratched by a good knife blade; and those with a hardness of less than 7 can be scratched by quartz.

In testing for hardness it is important to know not only that the scratching substance will actually scratch the substance being tested, but also that the latter will not scratch the former. Further, it is likewise important that the scratching substance be clean and fresh. If a cent or a knife blade is being used for scratching, it should be bright; if a mineral is being used, it should not be coated with a tarnish or a layer of weathered substance.

It is also to be remembered that the color of a mineral is its color on a fresh fracture and not on a weathered surface.

Again, it must be stated that the tables in this book are not expected to determine for their users the names of minerals; they are to serve merely as guides to the pages on which the minerals are described. Recourse must be had to the descriptions of the individual minerals before the nature of the substance being studied can be established.

KEY TO THE DETERMINATION OF MINERALS

A.—MINERALS WITH METALLIC LUSTER[1]

STREAK BLACK OR DARK GRAY

Color	Name	Hardness	Ref. Page	Color	Name	Hardness	Ref. Page
White or Light Gray	Lead	1.5	62	White or Light Gray	Arsenic	3–4	50
	Tetradymite	1.5–2	75		Domeykite	3.5	78
	Bismuthinite	2.0	74		Löllingite	5–5.5	113
	Jamesonite	2–2.5	122		Cobaltite	5.5	106
	Stibnite	2–2.5	72		Smaltite	5.5	107
	Calaverite	2–3	114		Arsenopyrite	5.5–6	111
	Galena	2.5	81		Chloanthite	5.5	108
	Clausthalite	2.5–3	84		Marcasite	6–6.5	109
	Stromeyerite	2.5–3	86		Sperrylite	6–7	108
Brassy Bronze	Calaverite	2–3	114	Brassy Bronze	Pentlandite	3.5–4	90
	Bornite	3–3.5	130		Pyrrhotite	3.5–4.5	92
	Millerite	3–3.5	95		Niccolite	5.5	95
	Domeykite	3.5	78		Pyrite	5–6.5	92
	Chalcopyrite	3.5–4	131		Marcasite	6–6.5	109
Dark Gray or Black	Molybdenite	1–1.5	75	Dark Gray or Black	Enargite	3	123
	Graphite	1–1.5	44		Tetrahedrite	3–4	126
	Pyrolusite	1–2	175		Arsenic	3–4	50
	Wad	1–2.5	189		Uraninite	3–5.5	297
	Melaconite	1–3	149		Staurolite	4	337
	Stibnite	2–2.5	72		Iron	4.5–5	655
	Jamesonite	2–2.5	122		Wolframite	5–5.5	258
	Polybasite	2–2.5	125		Psilomelane	5–6	188
	Pearceite	2–2.5	125		Ilmenite	5–6	462
	Stephanite	2–2.5	124		Magnetite	5.5–6.5	198
	Argentite	2–2.5	79		Franklinite	5.5–6.5	199
	Galena	2.5	81		Polianite	6–6.5	174
	Chalcocite	2.5–3	84		Braunite	6–6.5	204
	Bournonite	2.5–3	120		Columbite	6–6.5	293
	Stromeyerite	2.5–3	86		Tantalite	6–6.5	293
	Metacinnabarite	3	100		Corundum	7–9	155
Blue	Covellite	1.5–2	96				

[1] The references are to pages in this book.

A.—MINERALS WITH METALLIC LUSTER—(*Con.*)

STREAK BLACK OR DARK GRAY—(*Con.*)

Color	Name	Hardness	Ref. Page	Color	Name	Hardness	Ref. Page
Brown	Wad	1–3	189	Brown	Uraninite	3–5.5	297

STREAK BROWN

Color	Name	Hardness	Ref. Page	Color	Name	Hardness	Ref. Page
Dark Gray or Black	Wad	1–3	189	Dark Gray or Black	Wolframite	5–6	258
	Dufrenosite	2–3	275		Hornblende	5–6	388
	Hematite	2–3	153		Psilomelane	5–6	188
	Tetrahedrite	3–4	126		Ilmenite	5–6	462
	Uraninite	3–5.5	297		Samarskite	5–6	295
	Siderite	3.5–4	219		Chromite	5.5	200
	Sphalerite	3.5–4	87		Brookite	5.5–6	176
	Manganite	3.5–4	191		Fergusonite	5.5–6	293
	Wurtzite	3.5–4	90		Allanite	5.5–6	330
	Cuprite	3.5–4	147		Franklinite	5.5–6.5	199
	Triplite	4–5.5	273		Hematite	6–6.5	153
	Thorite	4.5–5.5	319		Columbite	6–6.5	293
	Goethite	4.5–5.5	193		Tantalite	6–6.5	293
	Limonite	4.5–5.5	183		Rutile	6–7	171
	Plattnerite	5–5.5	175		Cassiterite	6–7	168
	Hausmannite	5–5.5	204		Corundum	7–9	155
	Huebnerite	5–5.5	258		Spinel	7.5–8	196
Brown	Wad	1–3	189	Brown	Ilmenite	5–6	462
	Limonite	1–3	183		Limonite	5.5	183
	Hematite	1–6	153		Brookite	5.5–6	176
	Uraninite	3–5.5	297		Allanite	5.5–6	330
	Siderite	3.5–4	219		Franklinite	5.5–6.5	199
	Sphalerite	3.5–4	87		Hematite	6	153
	Wurtzite	3.5–4	90		Columbite	6–6.5	293
	Thorite	4–5	319		Tantalite	6–6.5	293
	Triplite	4–5.5	273		Braunite	6–6.5	204
	Limonite	4–5.5	183		Rutile	6–7	171
	Goethite	4.5–5.5	193		Cassiterite	6–7	168
	Huebnerite	4.5–5.5	258		Spinel	7.5–8	196
	Wolframite	5–6	258				
Yellow	Limonite	1–5.5	183	Yellow	Goethite	4.5–5.5	193
	Pentlandite	3.5–4	90		Huebnerite	4.5–5.5	258
	Siderite	3.5–4	219		Cassiterite	6–7	168
	Sphalerite	3.5–4	87		Spinel	7.5–8	196
	Thorite	4.5	319				

A.—MINERALS WITH METALLIC LUSTER—(*Con.*)

STREAK BROWN—(*Con.*)

Color	Name	Hardness	Ref. Page	Color	Name	Hardness	Ref. Page
Red	Cinnabar	2–2.5	98	Red	Breithauptite	5.5	95
	Cuprite	3.5–4	147		Rutile	6–7	171

STREAK RED

Color	Name	Hardness	Ref. Page	Color	Name	Hardness	Ref. Page
Dark Gray or Black	Wad	1–3	189	Dark Gray or Black	Cuprite	3.5–4	147
	Hematite	2–3	153		Wolframite	5–5.5	258
	Copper	2.5–3	53		Samarskite	5–6	295
	Pyrargyrite	2.5–3	117		Franklinite	5.5–6.5	199
	Tetrahedrite	3–4	126		Hematite	6–6.5	153
	Manganite	3.5–4	191		Columbite	6–6.5	293
Brown	Wad	1–3	189	Brown	Wolframite	5–5.5	258
	Hematite	2–3	153				
Red	Hematite	2–3	153	Red	Copper	2.5–3	53
	Cinnabar	2–2.5	98		Gold	2.5–3	58
	Proustite	2.5	119		Hematite	3–6	153
	Pyrargyrite	2.5–3	117		Breithauptite	5	95

STREAK YELLOW

Color	Name	Hardness	Ref. Page	Color	Name	Hardness	Ref. Page
Dark Gray or Black	Siderite	3.5–4	219	Dark Gray or Black	Hornblende	5–6	388
	Sphalerite	3.5–4	87		Samarskite	5–6	295
	Triplite	4–5.5	273		Brookite	5.5–6	176
	Goethite	4.5–5.5	193		Rutile	6–7	171
	Limonite	5–5.5	183		Cassiterite	6–7	168
	Huebnerite	5–5.5	258				
Brown	Limonite	1–5.5	183	Brown	Huebnerite	4.5–5.5	258
	Sphalerite	3.5–4	87		Limonite	5–5.5	183
	Zincite	4–4.5	150		Brookite	5.5–6	176
	Triplite	4–5.5	273		Rutile	6–7	171
	Goethite	4.5–5.5	193		Cassiterite	6–7	168
Yellow	Limonite	1–5.5	183	Yellow	Goethite	4.5–5.5	193
	Calaverite	2–3	114		Huebnerite	4.5–5.5	258
	Gold	2.5–3	58		Limonite	5–5.5	183
	Greenockite	3–3.5	91		Cassiterite	6–7	168
	Sphalerite	3.5–4	87				

A.—MINERALS WITH METALLIC LUSTER—(*Con.*)

STREAK YELLOW—(*Con.*)

Color	Name	Hardness	Ref. Page	Color	Name	Hardness	Ref. Page
Red	Sphalerite	3.5–4	87	Red	Brookite	55.–6	176
	Zincite	4–4.5	150		Rutile	6–7	171
	Goethite	4.5–5.5	193				

STREAK GREEN

Green	Uraninite	3–5.5	297	Green	Augite	5–6	374
	Alabandite	3.5	90		Gadolinite	6–7	335
	Hornblende	5–6	388		Spinel	7.5–8	196
Black, Brown or Red	Alabandite	3.5	90	Black, Brown or Red	Huebnerite	4.5–5.5	258
	Uraninite	3–5.5	297		Gadolinite	6–7	335

STREAK GRAY

Silver White	Sylvanite	1.5–2	114	Silver White	Antimony	3–4	51
	Tellurium	2–2.5	50		Dyscrasite	3.5	78
	Bismuth	2–2.5	50		Platinum	4–5	63
	Silver	2.5–3	55		Palladium	4–5	66
	Calaverite	2.5	114		Iridosmine	6–7	67
Dark Gray or Black	Molybdenite	1–1.5	75	Dark Gray or Black	Hornblende	5–6	388
	Graphite	1–2	44		Augite	5–6	374
	Tetradymite	1.5–2	75		Hypersthene	5–6	365
	Silver	2.5–3	55		Allanite	5.5–6	330
	Biotite	2.5–3	349		Anatase	5.5–6	176
	Hessite	2.5–3	79		Brookite	5.5–6	176
	Petzite	2.5–3	79		Perovskite	5.5–6	461
	Stromeyerite	2.5–3	86		Rutile	6–7	171
	Sphalerite	3.5–4	87		Gadolinite	6–7	335
	Titanite	5–5.5	464		Spinel	6–7	196
	Huebnerite	5–5.5	258				
Brown	Huebnerite	5–5.5	258	Brown	Perovskite	5.5–6	461
	Allanite	5.5–6	330		Rutile	6–7	171
	Anatase	5.5–6	176		Gadolinite	6–7	335
	Brookite	5.5–6	176		Cassiterite	6–7	168

A.—MINERALS WITH METALLIC LUSTER—(*Con.*)

STREAK WHITE

Color	Name	Hardness	Ref. Page	Color	Name	Hardness	Ref. Page
Silver White	Sylvanite.....	1–2	114	Silver White	Amalgam.....	3–3.5	63
	Silver.....	3	55		Antimony.....	3–4	51
	Altaite.....	3	84		Iridium.....	6–7	66
Dark Gray or Black	Biotite.....	2.5–3	349	Dark Gray or Black	Anatase.....	5.5–6	176
	Silver.....	2.5–3	55		Perovskite....	5.5–6	461
	Titanite.....	5–5.5	464		Cassiterite....	6–7	168
	Hornblende...	5–6	388		Garnet.....	6.5–7	312
	Augite.....	5–6	374		Tourmaline...	7–7.5	434
	Hypersthene..	5–6	365		Spinel.....	7.5–8	196
Brown	Anatase.....	5.5–6	176	Brown	Cassiterite....	6–7	168
	Perovskite....	5.5–6	461				

B.—MINERALS WITH NONMETALLIC LUSTER

STREAK DARK GRAY OR BLACK

Color	Name	Hardness	Ref. Page	Color	Name	Hardness	Ref. Page
Dark Gray or Black	Graphite.....	1–2	44	Dark Gray or Black	Wolframite....	5–5.5	258
	Melaconite....	1–2.5	149		Psilomelane...	5–6	188
	Wad.....	1–3	189		Corundum....	7–9	155
Brown	Wad.....	1–3	189				

STREAK BROWN

Dark Gray or Black	Wad.....	1–3	189	Dark Gray or Black	Hornblende...	5–6	388
	Uraninite.....	3–5.5	297		Psilomelane...	5–6	188
	Siderite.....	3.5–4	219		Chromite.....	5–6	200
	Sphalerite.....	3.5–4	87		Uraninite.....	5.5	297
	Cuprite.....	3.5–4	147		Allanite.....	5.5–6	330
	Thorite.....	4.5–5	319		Brookite.....	5.5–6	176
	Goethite.....	4.5–5.5	193		Rutile.....	6–7	171
	Ferberite.....	4.5–5.5	258		Cassiterite....	6–7	168
	Wolframite....	5–5.5	258		Spinel.....	7.5–8	196

B.—MINERALS WITH NONMETALLIC LUSTER—(*Con.*)

STREAK BROWN—(*Con.*)

Color	Name	Hardness	Ref. Page	Color	Name	Hardness	Ref. Page
Brown	Wad	1–3	189	Brown	Siderite	3–5.4	219
	Hematite	1–3	153		Sphalerite	3–5.4	87
	Limonite	1–3	183		Xenotime	4–5	265
	Bauxite	1–3	186		Thorite	4.5–5	319
	Cinnabar	2–2.5	98		Goethite	4.5–5	193
	Pharmaco-siderite	2.5	288		Huebnerite	5–5.5	258
	Chrysocolla	2–5	441		Wolframite	5–5.5	258
	Hematite	3	153		Hornblende	5–6	388
	Limonite	3	183		Allanite	5.5–6	330
	Bauxite	3	186		Brookite	5.5–6	176
	Olivenite	3	277		Rutile	6–7	171
	Uraninite	3–5.5	297		Cassiterite	6–7	168
					Spinel	7.5–8	196
Red	Hematite	1–3	153	Red	Huebnerite	4.5–5	258
	Cinnabar	2–2.5	98		Wolframite	5–5.5	258
	Hematite	3–6	153		Hematite	6	153
	Cuprite	3.5–4	147		Rutile	6–6.5	171
	Sphalerite	3.5–4	87		Cassiterite	6–7	168
	Xenotime	4–5	265				
Yellow	Bauxite	1–3	186	Yellow	Goethite	4.5–5.5	193
	Limonite	1–3	183				

STREAK RED

Dark Gray or Black	Hematite	1–3	153	Dark Gray or Black	Cuprite	3.5–4	147
					Hematite	5.5–6.5	153
Brown	Cinnabar	2–2.5	98	Brown	Hematite	3–6	153
Red	Bauxite	1–3	186	Red	Pyrargyrite	2.5–3	117
	Hematite	1–3	153		Crocoite	2.5–3	253
	Erythrite	1.5–2	282		Zincite	4.4–5	150
	Cinnabar	2–2.5	98		Xenotime	4–5	265
	Proustite	2–2.5	119		Wolframite	5–5.5	258
Yellow	Hematite	3–6	153				

B.—MINERALS WITH NONMETALLIC LUSTER—(*Con.*)

STREAK YELLOW

Color	Name	Hardness	Ref. Page	Color	Name	Hardness	Ref. Page
Dark Gray or Black	Siderite	3.5–4	219	Dark Gray or Black	Brookite	5.5–6	176
	Huebnerite	4.5–5	258		Rutile	6–7	171
	Goethite	4.5–5.5	193		Cassiterite	6–7	168
Brown	Wad	1–3	189	Brown	Huebnerite	4.5–5.5	258
	Limonite	1–3	183		Goethite	4.5–5.5	193
	Bauxite	1–3	186		Brookite	5.5–6	176
	Siderite	3.5–4	219		Rutile	6–7	171
	Sphalerite	3.5–4	87		Cassiterite	6–7	168
	Xenotime	4–5	265				
Red	Bauxite	1–3	186	Red	Zincite	4–4.5	150
	Wulfenite	3	257		Huebnerite	4.5–5.5	258
	Vanadinite	3	271		Rutile	6–7	171
	Sphalerite	3.5–4	87		Cassiterite	6–7	168
Yellow	Bauxite	1–3	186	Yellow	Wulfenite	3	257
	Limonite	1–3	183		Vanadinite	3	271
	Orpiment	1.5–2	71		Greenockite	3–3.5	91
	Sulphur	1.5–2	47		Pyromorphite	3.5–4	270
	Autunite	2–2.5	289		Sphalerite	3.5–4	87
	Carnotite	2–3	290		Zincite	4–4.5	150
	Pharmacosiderite	2.5	288		Goethite	4.5–5	193
					Crocidolite	5–6	292

STREAK ORANGE

Brown	Thorite	4.5–5	319				
Red	Realgar	1.5–2	69	Red	Crocoite	2–5	253
					Zincite	4–4.5	150
Yellow	Greenockite	3–3.5	91	Yellow	Thorite	4.5–5	319

STREAK GREEN

Dark Gray or Black	Uraninite	3–3.5	297	Dark Gray or Black	Augite	5–6	374
					Spinel	7.5–8	196

B.—MINERALS WITH NONMETALLIC LUSTER—(*Con.*)

STREAK GREEN—(*Con.*)

Color	Name	Hardness	Ref. Page	Color	Name	Hardness	Ref. Page
Green	Glauconite....	1–2	442	Green	Brochantite...	3–5	245
	Chlorite.....	1–2.5	428		Malachite.....	3.5–4	231
	Annabergite...	1–2.5	283		Pyromorphite .	3.5–4	270
	Torbernite....	2–2.5	289		Dufrenite.....	3.5–4	275
	Chrysocolla...	2–3	441		Libethenite ...	4	278
	Garnierite.....	2–3	400		Dioptase.....	5	347
	Pharmaco-siderite.....	2.5	288		Hornblende...	5–6	388
					Augite.....	5–6	374
	Olivenite.....	3	277		Turquoise.....	6	279
	Atacamite....	3–3.5	144		Chloritoid.....	6–7	427

STREAK BLUE

Blue	Vivianite.....	1.5–2	281	Blue	Lasurite.....	5–5.5	343
	Chrysocolla...	2–3	441		Glaucophane..	6–6.5	390
	Azurite.....	3.5–4	233		Dumortierite..	7	338
	Crocidolite....	4	392				
Green	Vivianite.....	1.5–2	281	Green	Dumortierite..	7	338
	Crocidolite....	4	392				

STREAK WHITE

Dark Gray or Black	Gypsum.....	1.5–2	247	Dark Gray or Black	Huebnerite....	4.5–5.5	258
	Halite.....	2–2.5	134		Titanite.....	5–5.5	464
	Apatite.....	2–5	266		Glaucophane..	5–5.5	390
	Biotite.....	2–5	349		Yttrotantalite.	5–5.5	295
	Calcite.....	3	214		Hornblende...	5–6	388
	Anhydrite.....	3–3.5	238		Augite.....	5–6	374
	Cerussite.....	3–3.5	227		Schefferite....	5–6	373
	Serpentine....	3–4	398		Hypersthene..	5–6	365
	Wavellite.....	3.5–4	287		Wagnerite....	5.5	273
	Ankerite.....	3.5–4	230		Allanite.....	5.5–6	330
	Dolomite.....	3.5–4	229		Anatase.....	5.5–6	176
	Sphalerite.....	3.5–4	87		Brookite.....	5.5–6	176
	Magnesite.....	3.5–5	218		Perovskite....	5.5–6	461
	Fluorite.....	4	139		Labradorite...	6–6.5	418

B.—MINERALS WITH NONMETALLIC LUSTER—(*Con.*)

STREAK WHITE—(*Con.*)

Color	Name	Hardness	Ref. Page	Color	Name	Hardness	Ref. Page
Dark Gray or Black	Epidote	6–7	327	Dark Gray or Black	Garnet	6.5–7.5	312
	Piedmontite	6–7	329		Quartz	7	159
	Chloritoid	6–7	427		Tourmaline	7–7.5	434
	Gadolinite	6–7	335		Staurolite	7–7.5	337
	Rutile	6–7	171		Spinel	7.5–8	196
	Cassiterite	6–7	168		Diamond	10	37
Brown	Cerargyrite	1–1.5	138	Brown	Skorodite	3.5–4	285
	Carnallite	1–2	142		Strontianite	3.5–4	225
	Pyrophyllite	1–2	406		Siderite	3.5–4	219
	Tripolite	1–2.5	180		Pyromorphite	3.5–4	270
	Kaolinite	1–2.5	404		Mimetite	3.5–4	271
	Gypsum	1.5–2	247		Rhodochrosite	3.5–4	220
	Halite	2–2.5	134		Magnesite	3.5–5	218
	Muscovite	2–3	355		Fluorite	4	139
	Zinnwaldite	2–3	352		Clintonite	4–5	426
	Phlogopite	2–3	350		Chabazite	4–5	456
	Apatite	2–3	266		Harmotome	4–5	449
	Greenockite	2–3	91		Xenotime	4–5	265
	Leadhillite	2.5–3	252		Wollastonite	4.5–5	368
	Biotite	2.5–3	349		Apatite	4.5–5	266
	Chrysotile	2.5–3	398		Calamine	4.5–5	396
	Stolzite	2.5–3	256		Huebnerite	4.5–5	258
	Senarmontite	2.5–3	152		Lithiophylite	4.5–5	262
	Barite	2.5–3.5	239		Smithsonite	5	221
	Vanadinite	3	271		Thomsonite	5–5.5	455
	Wulfenite	3	257		Datolite	5–5.5	334
	Calcite	3	214		Titanite	5–5.5	464
	Anglesite	3–3.5	242		Monazite	5–5.5	263
	Serpentine	3–4	398		Yttrotantalite	5–5.5	295
	Heulandite	3–4	446		Nephelite	5–6	314
	Stilbite	3–4	450		Anthophyllite	5–6	383
	Laumontite	3–4	451		Enstatite	5–6	365
	Apatite	3.5	266		Bronzite	5–6	365
	Dolomite	3.5–4	229		Hypersthene	5–6	365
	Sphalerite	3.5–4	87		Diopside	5–6	372
	Wavellite	3.5–4	287		Hornblende	5–6	388
	Aragonite	3.5–4	223				

B.—MINERALS WITH NONMETALLIC LUSTER—(*Con.*)

STREAK WHITE—(*Con.*)

Color	Name	Hardness	Ref. Page	Color	Name	Hardness	Ref. Page
Brown	Augite	5–6	374	Brown	Rutile	6–7	171
	Babingtonite	5–6	380		Gadolinite	6–7	335
	Acmite	5–6	375		Cassiterite	6–7	168
	Fowlerite	5–6	380		Andalusite	6–7.5	320
	Willemite	5–6	306		Vesuvianite	6.5	432
	Troostite	5–6	306		Olivine	6.5–7	303
	Opal	5.5–6	179		Garnet	6.5–7.5	312
	Allanite	5.5–6	330		Quartz	7	159
	Anatase	5.5–6	176		Boracite	7	210
	Brookite	5.5–6	176		Danburite	7–7.5	325
	Perovskite	5.5–6	461		Tourmaline	7–7.5	434
	Tephroite	6	305		Staurolite	7–7.5	337
	Amblygonite	6	274		Phenacite	7–8	307
	Chondrodite	6–6.5	333		Zircon	7.5	317
	Zoisite	6–6.5	326		Spinel	7.5–8	196
	Sillimanite	6–7	321		Chrysoberyl	8.5	202
	Axinite	6–7	345		Corundum	9	155
	Epidote	6–7	327		Diamond	10	37
	Diaspore	6–7	190				
Green	Cerargyrite	1–1.5	138	Green	Stolzite	2.5–3	256
	Glauconite	1–2	442		Phlogopite	2.5–3	350
	Pyrophyllite	1–2	406		Biotite	2.5–3	349
	Chrysotile	1–2.5	398		Barite	2.5–3	239
	Kaolinite	1–2.5	404		Gibbsite	2.5–3.5	182
	Vivianite	1–2.5	281		Wulfenite	3	257
	Talc	1–2.5	401		Anhydrite	3–3.5	238
	Chlorite	1–2.5	428		Anglesite	3–3.5	242
	Annabergite	1–2.5	283		Stilbite	3–4	450
	Orthochlorite	1–3	429		Serpentine	3–4	398
	Melanterite	2	251		Wavellite	3.5–4	287
	Halite	2–2.5	134		Aragonite	3.5–4	223
	Brucite	2–2.5	181		Scorodite	3.5–4	285
	Garnierite	2–3	400		Strontianite	3.5–4	225
	Zinnwaldite	2–3	352		Pyromorphite	3.5–4	270
	Actinolite	2–3	386		Rhodochrosite	3.5–4.5	220
	Chrysocolla	2–4	441		Fluorite	4	139
	Leptochlorite	2.5	432		Variscite	4	284

B.—MINERALS WITH NONMETALLIC LUSTER—(*Con.*)

STREAK WHITE—(*Con.*)

Color	Name	Hardness	Ref. Page	Color	Name	Hardness	Ref. Page
Green	Scheelite	4–5	254	Green	Amblygonite	6	274
	Apatite	4.5–5	266		Labradorite	6–6.5	418
	Calamine	4.5–5	396		Microcline	6–6.5	413
	Triphylite	4.5–5	262		Zoisite	6–6.5	326
	Smithsonite	5	221		Prehnite	6–6.5	343
	Datolite	5–5.5	334		Spodumene	6–7	378
	Cummingtonite	5–5.5	387		Forsterite	6–7	303
	Grünerite	5–5.5	387		Sillimanite	6–7	321
	Anthophyllite	5–5.5	383		Axinite	6–7	345
	Gedrite	5–5.5	383		Epidote	6–7	327
	Thomsonite	5–5.5	455		Piedmontite	6–7	329
	Titanite	5–5.5	464		Jadeite	6–7	377
	Wagnerite	5.5	273		Diaspore	6–7	190
	Hornblende	5–6	388		Chloritoid	6–7	427
	Augite	5–6	374		Gadolinite	6–7	335
	Acmite	5–6	375		Andalusite	6–7.5	320
	Hypersthene	5–6	365		Vesuvianite	6.5	432
	Cancrinite	5–6	315		Olivine	6.5	303
	Nephelite	5–6	314		Fayalite	6.5	303
	Scapolite	5–6	423		Uvarovite	6.5–7.5	313
	Actinolite	5–6	386		Quartz	7	159
	Enstatite	5–6	365		Boracite	7	210
	Bronzite	5–6	365		Tourmaline	7–7.5	434
	Diopside	5–6	372		Spinel	7.5–8	196
	Troostite	5–6	306		Beryl	7.5–8	359
	Opal	5–6	179		Topaz	8	322
	Turquoise	6	279		Chrysoberyl	8	202
					Corundum	9	155
Pink	Laumontite	1.5–2	451	Pink	Margarite	3–4.5	352
	Gypsum	1.5–2	247		Dolomite	3.5–4	229
	Zinnwaldite	1–2–3	352		Alunite	3.5–4	244
	Lepidolite	2–4	354		Rhodochrosite	3.5–4.5	220
	Glauberite	2.5	236		Fluorite	4	139
	Senarmontite	2.5–3	152		Xenotime	4–5	265
	Kainite	2.5–3	251		Apophyllite	4.5–5	443
	Calcite	3	214		Lithiophylite	4.5–5	262
	Laumontite	3–4	451		Datolite	5–5.5	334

B.—MINERALS WITH NONMETALLIC LUSTER—(*Con.*)

STREAK WHITE—(*Con.*)

Color	Name	Hardness	Ref. Page	Color	Name	Hardness	Ref. Page
Pink	Wagnerite	5.5	273	Pink	Zoisite	6–6.5	326
	Sodalite	5–6	340		Epidote	1–6–7	327
	Cancrinite	5–6	315		Andalusite	6–7.5	320
	Scapolite	5–6	423		Garnet	6.5–7	312
	Tremolite	5–6	386		Tourmaline	7–7.5	434
	Fowlerite	5–6	380		Spodumene	7–7.5	378
	Rhodonite	5–6	380		Phenacite	7–8	307
	Bustamite	5–6	380		Topaz	8	322
	Willemite	5–6	306		Spinel	8	196
	Tephroite	6	305		Corundum	9	155
	Orthoclase	6–6.5	413				
Red	Carnallite	1–2	142	Red	Ankerite	3.5–4	230
	Kaolinite	1–2.5	404		Alunite	3.5–4	244
	Talc	1–2.5	401		Sphalerite	3.5–4	87
	Laumontite	1–3	451		Rhodochrosite	3.5–4	220
	Gypsum	1.5–2	247		Clintonite	4–5	426
	Thenardite	2	237		Chabazite	4–5	456
	Sylvite	2–2.5	137		Harmotome	4–5	449
	Halite	2–2.5	134		Phillipsite	4–5	447
	Glauberite	2.5	236		Xenotime	4–5	265
	Phlogopite	2.5–3	350		Scheelite	4–5	254
	Stolzite	2.5–3	256		Apophyllite	4.5–5	443
	Gibbsite	2.5–3.5	182		Wollastonite	4.5–5	368
	Kainite	2.5–4	251		Apatite	4.5–5	266
	Cryolite	3	143		Huebnerite	4.5–5.3	258
	Calcite	3	214		Analcite	5–5.5	458
	Wulfenite	3	257		Natrolite	5–5.5	454
	Vanadinite	3	271		Thomsonite	5–5.5	455
	Anhydrite	3–3.5	238		Datolite	5–5.5	334
	Celestite	3–3.5	241		Titanite	5–5.5	464
	Barite	3–3.5	239		Monazite	5–5.5	263
	Stilbite	3–4	450		Cancrinite	5–6	315
	Heulandite	3–4	446		Nephelite	5–6	314
	Laumontite	3–4	451		Enstatite	5–6	365
	Serpentine	3–4	398		Diopside	5–6	372
	Dolomite	3.5–4	229		Rhodonite	5–6	380
	Aragonite	3.5–4	223		Willemite	5–6	306

B.—MINERALS WITH NONMETALLIC LUSTER—(*Con.*)

STREAK WHITE—(*Con.*)

Color	Name	Hardness	Ref. Page	Color	Name	Hardness	Ref. Page
	Troostite	5–6	306		Quartz	7	159
	Opal	5.5–6	179		Boracite	7	210
	Perovskite	5.5–6	461		Danburite	7–7.5	325
	Amblygonite	6	274		Tourmaline	7–7.5	434
	Orthoclase	6–6.5	413		Cordierite	7–7.5	438
Red	Chondrodite	6–6.5	333	Red	Phenacite	7–8	307
	Zoisite	6–6.5	326		Zircon	7.5	317
	Axinite	6–7	345		Beryl	7.5–8	359
	Epidote	6–7	327		Spinel	7.5–8	196
	Diaspore	6–7	190		Topaz	8	322
	Vesuvianite	6.5	432		Chrysoberyl	8.5	202
	Garnet	6.5–7.5	312		Corundum	9	155
	Cerargyrite	1–1.5	138		Vanadinite	3	271
	Carnallite	1–2	142		Celestite	3–3.5	241
	Pyrophyllite	1–2	406		Anglesite	3–3.5	242
	Tripolite	1–2.5	180		Cerussite	3–3.5	227
	Kaolinite	1–2.5	404		Heulandite	3–4	446
	Talc	1–2.5	401		Stilbite	3–4	450
	Chrysotile	1–3	398		Laumontite	3–4	451
	Orthochlorite	1–3	429		Serpentine	3–4	398
	Gypsum	1.5–2	247		Margarite	3–4.5	352
	Sulphur	1.5–2.5	47		Wavellite	3.5–4	287
	Hanksite	2	252		Dolomite	3.5–4	229
	Sylvite	2–2.5	137		Aragonite	3.5–4	223
Yellow	Halite	2–2.5	134	Yellow	Strontianite	3.5–4	225
	Muscovite	2–3	355		Sphalerite	3.5–4	87
	Phlogopite	2–3	350		Pyromorphite	3.5–4	270
	Gaylussite	2–3	235		Mimetite	3.5–4	271
	Zinnwaldite	2–3	352		Rhodochrosite	3.5–4.5	220
	Glauberite	2.5	236		Magnesite	3.5–5	218
	Leadhillite	2.5	252		Fluorite	4	139
	Kainite	2.5	251		Chabazite	4–5	456
	Trona	2.5–3	235		Harmotome	4–5	449
	Gibbsite	2.5–3.5	182		Phillipsite	4–5	447
	Barite	2.5–3.5	239		Xenotime	4–5	265
	Calcite	3	214		Scheelite	4.5	254
	Kieserite	3	246		Wollastonite	4.5–5	368
	Wulfenite	3	257				

B.—MINERALS WITH NONMETALLIC LUSTER—(*Con.*)

STREAK WHITE—(*Con.*)

Color	Name	Hardness	Ref. Page	Color	Name	Hardness	Ref. Page
Yellow	Apatite	4.5–5	266	Yellow	Willemite	5–6	306
	Calamine	4.5–5	396		Opal	5–6	179
	Huebnerite	4.5–5	258		Orthoclase	6–6.5	413
	Lithiophylite	4.5–5	262		Chondrodite	6–6.5	333
	Smithsonite	5	221		Epidote	6–7	327
	Natrolite	5–5.5	454		Rutile	6–7	171
	Thomsonite	5–5.5	455		Cassiterite	6–7	168
	Datolite	5–5.5	334		Andalusite	6–7.5	320
	Titanite	5–5.5	464		Olivine	6.5–7	303
	Monazite	5–5.5	263		Garnet	6.5–7	312
	Wagnerite	5–5.5	273		Quartz	7	159
	Sodalite	5–6	340		Tourmaline	7–7.5	434
	Cancrinite	5–6	315		Zircon	7.5	317
	Nephelite	5–6	314		Topaz	8	322
	Scapolite	5–6	423		Spinel	8	196
	Rhodonite	5–6	380		Corundum	9	155
Blue	Kaolinite	1–2.5	404	Blue	Smithsonite	5	221
	Vivianite	1–2.5	281		Lasurite	5–5.5	343
	Sylvite	2–2.5	137		Lazulite	5–5.5	275
	Halite	2–2.5	134		Haüynite	5–6	341
	Brucite	2–2.5	181		Sodalite	5–6	340
	Chrysocolla	2–4	441		Cancrinite	5–6	315
	Chalcanthite	2–5	246		Nephelite	5–6	314
	Barite	2.5–3.5	239		Scapolite	5–6	423
	Calcite	3	214		Willemite	5–6	306
	Gibbsite	3–3.5	182		Diopside	5–6	372
	Anhydrite	3–3.5	238		Opal	5.5–6	179
	Celestite	3–3.5	241		Turquoise	6	279
	Anglesite	3–3.5	242		Amblygonite	6	274
	Aragonite	3.5–4	223		Glaucophane	6–6.5	390
	Wavellite	3.5–4	287		Axinite	6–7	345
	Skorodite	3.5–4	285		Diaspore	6–7	190
	Fluorite	4	139		Kyanite	6–7	393
	Kyanite	4–5	393		Vesuvianite	6–7	432
	Apatite	4.5–5	266		Quartz	7	159
	Calamine	4.5–5	396		Boracite	7	210
	Triphylite	4.5–5	262		Cordierite	7–7.5	438

B.—MINERALS WITH NONMETALLIC LUSTER—(*Con.*)

STREAK WHITE—(*Con.*)

Color	Name	Hardness	Ref. Page	Color	Name	Hardness	Ref. Page
Blue	Tourmaline	7–7.5	434	Blue	Spinel	7.5–8	196
	Beryl	7.5–8	359		Topaz	8	322
					Corundum	9	155
Purple	Halite	2–2.5	134	Purple	Quartz	7	159
	Calcite	3	214		Spodumene	7–7.5	378
	Fluorite	4	139		Topaz	8	322
	Apatite	4.5–5	266		Spinel	8	196
	Scapolite	5–6	423		Corundum	9	155
	Tremolite	5–6	386				
Bronze	Phlogopite	2.5–3	350				
Orange	Vanadinite	3	271	Orange	Spinel	8	196

STREAK COLORLESS OR WHITE

White or Light Gray	Soda	1–1.5	234	White or Light Gray	Halite	2–2.5	134
	Cerargyrite	1–1.5	138		Brucite	2.2–5	181
	Arsenolite	1–2	152		Pharmacolite	2–2.5	292
	Carnallite	1–2	142		Senarmontite	2–2.5	152
	Chrysotile	1–2.5	398		Kainite	2–3	251
	Tripolite	1–2.5	180		Muscovite	2–3	355
	Calcite	1–2.5	214		Paragonite	2–3	358
	Talc	1–2.5	401		Zinnwaldite	2–3	352
	Pyrophyllite	1–2.5	406		Grünerite	2–3	387
	Orthochlorite	1–3	429		Gaylussite	2–3	235
	Bauxite	1–3	186		Lepidolite	2–4	354
	Mirabilite	1.5–2	246		Apatite	2–5	266
	Niter	1.5–2	206		Glauberite	2–5	236
	Soda-niter	1.5–2	205		Claudetite	2–5	152
	Gypsum	1.5–2	247		Stolzite	2.5–3	256
	Vivianite	1.5–2	281		Trona	2.5–3	235
	Melanterite	1.5–2	251		Cryolite	2.5–3	143
	Meerschaum	2	401		Gibbsite	2.5–3	182
	Hanksite	2	252		Barite	2.5–3	239
	Thenardite	2	237		Valentinite	2.5–3	152
	Kaolinite	2–2.5	404		Kieserite	3	246
	Borax	2–2.5	207		Calcite	3	214
	Epsomite	2–2.5	250		Wulfenite	3	257
	Sylvite	2–2.5	137		Anhydrite	3–3.5	238

B.—MINERALS WITH NONMETALLIC LUSTER—(*Con.*)

STREAK COLORLESS OR WHITE—(*Con.*)

Color	Name	Hardness	Ref. Page	Color	Name	Hardness	Ref. Page
	Celestite	3–3.5	241		Nephelite	5–6	314
	Anglesite	3–3.5	242		Scapolite	5–6	423
	Cerussite	3–3.5	227		Tremolite	5–6	386
	Heulandite	3–4	446		Anthophyllite	5–6	443
	Stilbite	3–4	450		Enstatite	5–6	365
	Laumontite	3–4	451		Diopside	5–6	372
	Margarite	3–4.5	352		Willemite	5–6	306
	Andulusite	3–6	320		Gedrite	5.5–6	383
	Alunite	3.5–4	244		Opal	5.5–6	179
	Wavellite	3.5–4	287		Leucite	5.5–6	362
	Dolomite	3.5–4	229		Beryllonite	5.5–6	263
	Aragonite	3.5–4	223		Amblygonite	6	274
	Strontianite	3.5–4	225		Orthoclase	6–6.5	413
	Siderite	3.5–4	219		Microcline	6–6.5	413
	Ankerite	3.5–4	230		Plagioclase	6–6.5	418
	Witherite	3.5–4	226		Prehnite	6–7	343
	Pyromorphite	3.5–4	270		Spodumene	6–7	378
	Mimetite	3.5–4	271		Sillimanite	6–7	321
White	Rhodochrosite	3.5–4.5	220	White	Jadeite	6–7	377
or	Magnesite	3.5–4.5	218	or	Axinite	6–7	345
Light	Fluorite	4	134	Light	Zoisite	6–7	326
Gray	Colemanite	4–5	208	Gray	Diaspore	6–7	190
	Chabazite	4–5	456		Kyanite	6–7	393
	Apophyllite	4–5	443		Andalusite	6–7.5	320
	Harmotome	4–5	449		Californite	6.5	434
	Phillipsite	4–5	447		Garnet	6.5–7.5	312
	Pectolite	4–5	369		Quartz	7	159
	Kyanite	4–5	393		Dumortierite	7	338
	Scheelite	4–5	254		Boracite	7	210
	Wollastonite	4.5–5	368		Cordierite	7–7.5	438
	Apatite	4.5–5	266		Danburite	7–7.5	325
	Calamine	4.5–5	396		Tourmaline	7–7.5	434
	Smithsonite	5	221		Phenacite	7–8	307
	Analcite	5–5.5	458		Zircon	7.5	317
	Thomsonite	5–5.5	455		Beryl	7.5–8	359
	Natrolite	5–5.5	454		Topaz	8	322
	Datolite	5–5.5	334		Chrysoberyl	8.5	202
	Scolecite	5–5.5	452		Corundum	9	155
	Sodalite	5–6	340		Diamond	10	37
	Cancrinite	5–6	315				

II. LIST OF THE MORE IMPORTANT MINERALS ARRANGED ACCORDING TO THEIR PRINCIPAL CONSTITUENTS

ALUMINIUM

Albite
Alum
Alunite
Amblygonite
Analcite
Andalusite
Anorthite
Augite
Axinite
Bauxite
Beryl
Brittle micas
Cancrinite
Celsian
Chabazite
Chrysoberyl
Cordierite
Corundum
Cryolite
Cyanite
Diaspore
Dumortierite
Epidote
Feldspars
Garnet
Gibbsite
Glaucophane
Harmotome
Heulandite
Hornblende
Jadeite
Kaolin
Kyanite
Laumontite
Lazulite
Lazurite
Lepidolite
Leucite
Margarite
Micas
Microcline
Natrolite
Nephelite
Orthoclase
Piedmontite
Prehnite
Pyrophyllite
Sillimanite
Sodalite
Spinel
Spodumene
Staurolite
Stilbite
Thomsonite
Topaz
Tourmaline
Turquoise
Uvarovite
Variscite
Vesuvianite
Wavelite
Zeolite
Zoisite
Many other silicates

ANTIMONY

Antimony
Bournonite
Breithauptite
Dyscrasite
Jamesonite
Pyrargyrite
Senarmontite
Stephanite
Stibnite
Sulphantimonites
Tetrahedrite
Valentinite

ARSENIC

Arsenates
Arsenic
Arsenolite
Arsenopyrite
Chloanthite
Claudetite
Cobaltite
Domeykite
Enargite
Erythrite
Gersdorffite
Löllingite
Mimetite
Niccolite
Olivenite
Orpiment
Proustite
Realgar
Scorodite
Smaltite
Sperrylite
Sulpharsenites
Tennantite

BARIUM

Barite
Celsian
Harmotome
Hyalophane
Psilomelane
Witherite

BERYLLIUM

Bertrandite
Beryl
Beryllonite
Chrysoberyl
Gadolinite
Herderite
Phenacite

BISMUTH

Bismite
Bismuth
Bismuthinite
Bismutite
Sulpho-bismuthinites
Tetradymite

BORON

Axinite
Boracite
Borax
Colemanite
Danburite
Datolite
Dumortierite
Sassolite
Tourmaline
Ulexite

BROMINE

Bromyrite
Embolite
Iodobromite

CADMIUM

Greenockite

CÆSIUM

Pollucite

CALCIUM

Actinolite
Andradite
Anhydrite
Ankerite
Anorthite
Apatite
Apophyllite
Aragonite
Asbestus
Augite
Autunite
Babingtonite
Bustamite
Calcite
Cancrinite
Carnotite
Chabazite
Colemanite
Danburite
Datolite
Diopside
Dolomite
Epidote
Fluorite
Gaylussite
Glauberite
Grossularite
Gypsum
Harmotome
Heulandite
Hornblende
Laumontite
Margarite
Perovskite
Phillipsite
Piedmontite
Prehnite
Scheelite
Scolecite
Stilbite
Thomsonite
Titanite
Tremolite
Uvarovite
Vesuvianite
Wollastonite
Zoisite
Many other silicates

CARBON

Cancrinite
Carbonates
Diamond
Graphite
Hanksite

CERIUM

Allanite
Fergusonite
Gadolinite
Monazite
Samarskite
Thorite
Xenotime

CHLORINE

Apatite
Atacamite
Boracite
Carnallite
Cerargyrite
Cryolite
Halite
Hanksite
Kainite
Mimetite
Pyromorphite
Scapolite
Sodalite
Sylvite
Vanadinite

CHROMIUM

Chromite
Crocoite
Uvarovite

COBALT

Cobaltite
Erythrite
Glaucodite
Linnaeite
Smaltite

COLUMBIUM

Columbite
Columbates
Fergusonite
Samarskite
Polycrase
Tantalite
Ytrrotantalite

COPPER

Atacamite
Azurite
Berzelianite
Bornite
Bournonite
Brochantite
Chalcanthite
Chalcocite
Chalcopyrite
Chrysocolla
Copper
Covellite
Cuprite
Cyprine
Dioptase
Domeykite
Enargite
Libethenite
Malachite
Melaconite
Olivenite
Stromeyerite
Tennantite
Tetrahedrite
Tenorite
Torbernite
Turquoise

DIDYMIUM

Allanite
Cerite
Gadolinite
Monazite

B.—MINERALS WITH NONMETALLIC LUSTER—(*Con.*)

STREAK WHITE—(*Con.*)

Color	Name	Hardness	Ref. Page	Color	Name	Hardness	Ref. Page
Pink	Wagnerite	5.5	273	Pink	Zoisite	6–6.5	326
	Sodalite	5–6	340		Epidote	1–6–7	327
	Cancrinite	5–6	315		Andalusite	6–7.5	320
	Scapolite	5–6	423		Garnet	6.5–7	312
	Tremolite	5–6	386		Tourmaline	7–7.5	434
	Fowlerite	5–6	380		Spodumene	7–7.5	378
	Rhodonite	5–6	380		Phenacite	7–8	307
	Bustamite	5–6	380		Topaz	8	322
	Willemite	5–6	306		Spinel	8	196
	Tephroite	6	305		Corundum	9	155
	Orthoclase	6–6.5	413				
Red	Carnallite	1–2	142	Red	Ankerite	3.5–4	230
	Kaolinite	1–2.5	404		Alunite	3.5–4	244
	Talc	1–2.5	401		Sphalerite	3.5–4	87
	Laumontite	1–3	451		Rhodochrosite	3.5–4	220
	Gypsum	1.5–2	247		Clintonite	4–5	426
	Thenardite	2	237		Chabazite	4–5	456
	Sylvite	2–2.5	137		Harmotome	4–5	449
	Halite	2–2.5	134		Phillipsite	4–5	447
	Glauberite	2.5	236		Xenotime	4–5	265
	Phlogopite	2.5–3	350		Scheelite	4–5	254
	Stolzite	2.5–3	256		Apophyllite	4.5–5	443
	Gibbsite	2.5–3.5	182		Wollastonite	4.5–5	368
	Kainite	2.5–4	251		Apatite	4.5–5	266
	Cryolite	3	143		Huebnerite	4.5–5.3	258
	Calcite	3	214		Analcite	5–5.5	458
	Wulfenite	3	257		Natrolite	5–5.5	454
	Vanadinite	3	271		Thomsonite	5–5.5	455
	Anhydrite	3–3.5	238		Datolite	5–5.5	334
	Celestite	3–3.5	241		Titanite	5–5.5	464
	Barite	3–3.5	239		Monazite	5–5.5	263
	Stilbite	3–4	450		Cancrinite	5–6	315
	Heulandite	3–4	446		Nephelite	5–6	314
	Laumontite	3–4	451		Enstatite	5–6	365
	Serpentine	3–4	398		Diopside	5–[illegible]	
	Dolomite	3.5–4	229		Rhodonite	[illegible]	
	Aragonite	3.5–4	223		Willemite	[illegible]	

B.—MINERALS WITH NONMETALLIC LUSTER—(*Con.*)

STREAK WHITE—(*Con.*)

Color	Name	Hardness	Ref. Page	Color	Name	Hardness	Ref. Page
	Troostite	5–6	306		Quartz	7	159
	Opal	5.5–6	179		Boracite	7	210
	Perovskite	5.5–6	461		Danburite	7–7.5	325
	Amblygonite	6	274		Tourmaline	7–7.5	434
	Orthoclase	6–6.5	413		Cordierite	7–7.5	438
Red	Chondrodite	6–6.5	333	Red	Phenacite	7–8	307
	Zoisite	6–6.5	326		Zircon	7.5	317
	Axinite	6–7	345		Beryl	7.5–8	359
	Epidote	6–7	327		Spinel	7.5–8	196
	Diaspore	6–7	190		Topaz	8	322
	Vesuvianite	6.5	432		Chrysoberyl	8.5	202
	Garnet	6.5–7.5	312		Corundum	9	155
	Cerargyrite	1–1.5	138		Vanadinite	3	271
	Carnallite	1–2	142		Celestite	3–3.5	241
	Pyrophyllite	1–2	406		Anglesite	3–3.5	242
	Tripolite	1–2.5	180		Cerussite	3–3.5	227
	Kaolinite	1–2.5	404		Heulandite	3–4	446
	Talc	1–2.5	401		Stilbite	3–4	450
	Chrysotile	1–3	398		Laumontite	3–4	451
	Orthochlorite	1–3	429		Serpentine	3–4	398
	Gypsum	1.5–2	247		Margarite	3–4.5	352
	Sulphur	1.5–2.5	47		Wavellite	3.5–4	287
	Hanksite	2	252		Dolomite	3.5–4	229
	Sylvite	2–2.5	137		Aragonite	3.5–4	223
Yellow	Halite	2–2.5	134	Yellow	Strontianite	3.5–4	225
	Muscovite	2–3	355		Sphalerite	3.5–4	87
	Phlogopite	2–3	350		Pyromorphite	3.5–4	270
	Gaylussite	2–3	235		Mimetite	3.5–4	271
	Zinnwaldite	2–3	352		Rhodochrosite	3.5–4.5	220
	Glauberite	2.5	236		Magnesite	3.5–5	218
	Leadhillite	2.5	252		Fluorite	4	139
	Kainite	2.5	251		Chabazite	4–5	456
	Trona	2.5–3	235		Harmotome	4–5	449
	Gibbsite	2.5–3.5	182		Phillipsite	4–5	447
	Barite	2.5–3.5	239		Xenotime	4–5	265
	Calcite	3	214		Scheelite	4.5	254
	Kieserite	3	246		Wollastonite	4.5–5	368
	Wulfenite	3	257				

B.—MINERALS WITH NONMETALLIC LUSTER—(*Con.*)

STREAK WHITE—(*Con.*)

Color	Name	Hardness	Ref. Page	Color	Name	Hardness	Ref. Page
Yellow	Apatite	4.5–5	266	Yellow	Willemite	5–6	306
	Calamine	4.5–5	396		Opal	5–6	179
	Huebnerite	4.5–5	258		Orthoclase	6–6.5	413
	Lithiophylite	4.5–5	262		Chondrodite	6–6.5	333
	Smithsonite	5	221		Epidote	6–7	327
	Natrolite	5–5.5	454		Rutile	6–7	171
	Thomsonite	5–5.5	455		Cassiterite	6–7	168
	Datolite	5–5.5	334		Andalusite	6–7.5	320
	Titanite	5–5.5	464		Olivine	6.5–7	303
	Monazite	5–5.5	263		Garnet	6.5–7	312
	Wagnerite	5–5.5	273		Quartz	7	159
	Sodalite	5–6	340		Tourmaline	7–7.5	434
	Cancrinite	5–6	315		Zircon	7.5	317
	Nephelite	5–6	314		Topaz	8	322
	Scapolite	5–6	423		Spinel	8	196
	Rhodonite	5–6	380		Corundum	9	155
Blue	Kaolinite	1–2.5	404	Blue	Smithsonite	5	221
	Vivianite	1–2.5	281		Lasurite	5–5.5	343
	Sylvite	2–2.5	137		Lazulite	5–5.5	275
	Halite	2–2.5	134		Haüynite	5–6	341
	Brucite	2–2.5	181		Sodalite	5–6	340
	Chrysocolla	2–4	441		Cancrinite	5–6	315
	Chalcanthite	2–5	246		Nephelite	5–6	314
	Barite	2.5–3.5	239		Scapolite	5–6	423
	Calcite	3	214		Willemite	5–6	306
	Gibbsite	3–3.5	182		Diopside	5–6	372
	Anhydrite	3–3.5	238		Opal	5.5–6	179
	Celestite	3–3.5	241		Turquoise	6	279
	Anglesite	3–3.5	242		Amblygonite	6	274
	Aragonite	3.5–4	223		Glaucophane	6–6.5	390
	Wavellite	3.5–4	287		Axinite	6–7	345
	Skorodite	3.5–4	285		Diaspore	6–7	190
	Fluorite	4	139		Kyanite	6–7	393
	Kyanite	4–5	393		Vesuvianite	6–7	432
	Apatite	4.5–5	266		Quartz	7	159
	Calamine	4.5–5	396		Boracite	7	210
	Triphylite	4.5–5	262		Cordierite	7–7.5	438

B.—MINERALS WITH NONMETALLIC LUSTER—(*Con.*)

STREAK WHITE—(*Con.*)

Color	Name	Hardness	Ref. Page	Color	Name	Hardness	Ref. Page
Blue	Tourmaline	7–7.5	434	Blue	Spinel	7.5–8	196
	Beryl	7.5–8	359		Topaz	8	322
					Corundum	9	155
Purple	Halite	2–2.5	134	Purple	Quartz	7	159
	Calcite	3	214		Spodumene	7–7.5	378
	Fluorite	4	139		Topaz	8	322
	Apatite	4.5–5	266		Spinel	8	196
	Scapolite	5–6	423		Corundum	9	155
	Tremolite	5–6	386				
Bronze	Phlogopite	2.5–3	350				
Orange	Vanadinite	3	271	Orange	Spinel	8	196

STREAK COLORLESS OR WHITE

White or Light Gray	Soda	1–1.5	234	White or Light Gray	Halite	2–2.5	134
	Cerargyrite	1–1.5	138		Brucite	2.2–5	181
	Arsenolite	1–2	152		Pharmacolite	2–2.5	292
	Carnallite	1–2	142		Senarmontite	2–2.5	152
	Chrysotile	1–2.5	398		Kainite	2–3	251
	Tripolite	1–2.5	180		Muscovite	2–3	355
	Calcite	1–2.5	214		Paragonite	2–3	358
	Talc	1–2.5	401		Zinnwaldite	2–3	352
	Pyrophyllite	1–2.5	406		Grünerite	2–3	387
	Orthochlorite	1–3	429		Gaylussite	2–3	235
	Bauxite	1–3	186		Lepidolite	2–4	354
	Mirabilite	1.5–2	246		Apatite	2–5	266
	Niter	1.5–2	206		Glauberite	2–5	236
	Soda-niter	1.5–2	205		Claudetite	2–5	152
	Gypsum	1.5–2	247		Stolzite	2.5–3	256
	Vivianite	1.5–2	281		Trona	2.5–3	235
	Melanterite	1.5–2	251		Cryolite	2.5–3	143
	Meerschaum	2	401		Gibbsite	2.5–3	182
	Hanksite	2	252		Barite	2.5–3	239
	Thenardite	2	237		Valentinite	2.5–3	152
	Kaolinite	2–2.5	404		Kieserite	3	246
	Borax	2–2.5	207		Calcite	3	214
	Epsomite	2–2.5	250		Wulfenite	3	257
	Sylvite	2–2.5	137		Anhydrite	3–3.5	238

THALLIUM

Crookesite
Lorandite

THORIUM

Aeschynite
Monazite
Pyrochlore
Thorite
Uraninite
Yttrialite

TIN

Canfieldite
Cassiterite
Stannite

TITANIUM

Anatase
Astrophyllite
Brookite
Ilmenite
Perovskite
Pseudobrookite
Rutile
Schorlomite
Titanite

TUNGSTEN

Ferberite
Huebnerite
Polycrase
Scheelite
Stolzite
Wolframite

URANIUM

Autunite
Carnotite
Gummite
Torbernite
Uraninite
Uranophane

VANADIUM

Carnotite
Descloizite
Patronite
Roscoelite
Vanadinite

YTTRIUM

Allanite
Fergusonite
Gadolinite
Samarskite
Xenotime
Yttrialite
Yttrotantalite

ZINC

Calamine
Fowlerite
Franklinite
Gahnite
Goslarite
Hydrozincite
Smithsonite
Sphalerite
Troostite
Willemite
Wurtzite
Zincite

ZIRCONIUM

Baddeleyite
Zircon

YIELDING WATER IN CLOSED TUBE

Allanite
Alunite
Analcite
Annabergite
Apophyllite
Atacamite
Autunite
Axinite
Azurite
Bauxite
Biotite
Borax
Brochantite
Brittle micas
Brucite
Calamine
Cancrinite
Carnallite
Chlorites
Chondrodite
Chrysocolla
Chrysotile
Colemanite
Cordierite
Datolite
Diaspore
Dioptase
Dufrenite
Dumortierite
Epidote
Epsomite
Garnierite
Gaylussite
Gibbsite
Glauconite
Goethite
Gypsum
Kainite
Kaolinite
Kieserite
Lazulite
Leadhillite
Lepidolite
Libethenite
Limonite
Malachite
Manganite
Margarite
Meerschaum
Micas
Mirabilite
Muscovite
Olivenite
Opal
Piedmontite
Pharmacolite
Pharmacosiderite
Phlogopite
Prehnite
Psilomelane
Pyrophyllite
Skorodite
Serpentine
Staurolite
Steatite
Struvite
Torbernite
Tourmaline
Topaz
Trona
Turquoise
Variscite
Vesuvianite
Vivianite
Wad
Wavellite
Zeolites
Zinnwaldite
Zoisite

III. LIST OF MINERALS ARRANGED ACCORDING TO THEIR CRYSTALLIZATION

AMORPHOUS (*probably colloidal*)

Bauxite
Chrysocolla
Garnierite
Glauconite
Limonite
Opal
Psilomelane
Pyrolusite (?)
Skorodite
Turquoise
Wad

ISOMETRIC

Arsenolite (?)
Boracite above 265°
α-Cristobalite
Lasurite
Leucite above 500°
Senarmontite (?)
Uraninite

HEXOCTAHEDRAL CLASS (HOLOHEDRAL)

Altaite	Franklinite	Magnetite
Amalgam	Gahnite	Mercury
Argentite	Galena	Palladium
Bornite	Garnet	Petzite
Cerargyrite	Gold	Picotite
Chromite	Halite	Platinum
Clausthalite	Hessite	Schorlomite
Copper	Iron	Silver
Fluorite	Lead	Spinel

DYAKISDODECAHEDRAL CLASS (HEMIHEDRAL)

Alum	Cobaltite	Smaltite
Chloanthite	Pyrite	Sperrylite

HEXTETRAHEDRAL CLASS (HEMIHEDRAL)

Alabandite	Noselite	Sphalerite
Boracite	Pentlandite	Tetrahedrite
Diamond	Perovskite (?)	Tennantite
Haüynite	Pharmacosiderite	Tiemannite
Metacinnabarite	Sodalite	

PENTAGONAL ICOSITETRAHEDRAL CLASS (HEMIHEDRAL)

Cuprite	Sylvite

PSEUDO-ISOMETRIC

Analcite	Leucite	Perovskite

HEXAGONAL

Breithauptite	Hanksite	Pyrrhotite (?)
Carnotite (?)	Molybdenite	β Tridymite
Covellite	Niccolite	

DIHEXAGONAL BIPYRAMIDAL CLASS (HOLOHEDRAL)

Beryl	Cancrinite

DIHEXAGONAL PYRAMIDAL CLASS (HOLO-HEMIMORPHIC)

Greenockite	Wurtzite	Zincite

HEXAGONAL BIPYRAMIDAL CLASS (HEMIHEDRAL)

Apatite	Mimetite	Pyromorphite	Vanadinite

HEXAGONAL PYRAMIDAL CLASS (HEMIHEDRAL-HEMIMORPHIC)

Nephelite

HEXAGONAL TRAPEZOHEDRAL CLASS (HEMIHEDRAL)

β Quartz

DITRIGONAL SCALENOHEDRAL CLASS (HEMIHEDRAL)

Alunite	Corundum	Selenium
Antimony	Graphite	Siderite
Arsenic	Hematite	Smithsonite
Bismuth	Iridosmine (?)	Soda-niter
Brucite	Magnesite	Tellurium
Calcite	Millerite	Tetradymite
Chabazite	Rhodochrosite	

DITRIGONAL PYRAMIDAL CLASS (HEMIHEDRAL-HEMIMORPHIC)

Ice	Tourmaline	Proustite	Pyrargyrite

TRIGONAL TRAPEZOHEDRAL CLASS (TETARTOHEDRAL)

Quartz	Cinnabar

TRIGONAL RHOMBOHEDRAL CLASS (TETARTOHEDRAL)

Ankerite	Phenacite	Willemite
Dioptase	Troostite	Dolomite
Ilmenite		

TETRAGONAL

α Cristobalite (?)

DITETRAGONAL BIPYRAMIDAL CLASS (HOLOHEDRAL)

Anatase	Phosgenite	Rutile
Apophyllite	Plattnerite	Vesuvianite
Braunite	Polianite	Xenotime
Cassiterite	Thorite	Zircon
Hausmannite	Torbernite	

TETRAGONAL SCALENOHEDRAL CLASS (HEMIHEDRAL)

Chalcopyrite

TETRAGONAL BIPYRAMIDAL CLASS (HEMIHEDRAL)

Marialite
Meionite
Mizzonite
Scapolite
Scheelite
Wernerite
Wulfenite

ORTHORHOMBIC

Acanthite
Anthophyllite (?)
Boracite below 265°
Bronzite (?)
Brookite
Chrysotile (?)
Columbite
Domeykite
Dufrenite
Dumortierite
Enstatite (?)
Gedrite (?)
Hypersthene (?)
Jamesonite
Kaolinite (?)
Meerschaum (?)
Perovskite (?)
Pyrophyllite (?)
Samarskite
Serpentine (?)
Steatite (?)
Tantalite
α Tridymite
Thomsonite
Variscite
Yitrotantalite

ORTHORHOMBIC BIPYRAMIDAL CLASS (HOLOHEDRAL)

Andalusite
Anhydrite
Anglesite
Aragonite
Arsenopyrite
Atacamite
Autunite
Barite
Beryllonite
Bismuthinite
Bournonite
Brochantite
Brookite
Carnallite
Celestite
Cerussite
Chalcocite
Chrysoberyl
Cordierite
Danburite
Diaspore
Dyskrasite
Enargite
Fayalite
Forsterite
Glaucodot
Goethite
Libethenite
Lithiophilite
Löllingite
Manganite
Marcasite
Natrolite
Niter
Olivenite
Olivine
Sillimanite
Skorodite
Staurolite
Stephanite
Stibnite
Stromeyerite
Strontianite
Sulphur
Tephroite
Thenardite
Topaz
α Tridymite
Triphylite
Valentinite
Wavellite
Witherite
Zoisite

ORTHORHOMBIC BISPHENOIDAL CLASS (HEMIHEDRAL)

Epsomite

ORTHORHOMBIC PYRAMIDAL CLASS (HEMIMORPHIC)

Bertrandite
Calamine
Prehnite
Stephanite
Struvite

MONOCLINIC

Anthophyllite (?)
Antigorite
Bronzite (?)
Chlorites
Chloritoid
Clinochlore
Clintonite
Durangite
Enstatite (?)
Gedrite (?)
Gibbsite
Herderite
Hypersthene (?)
Kaolinite (?)
Meerschaum (?)
Natron
Penninite
Prochlorite
Pyrophyllite (?)
Serpentine (?)
Steatite (?)

MONOCLINIC PRISMATIC CLASS (HOLOHEDRAL)

Acmite
Actinolite
Adularia
Algirine
Allanite
Annabergite
Anomite
Amphibole
Arfvedsonite
Augite
Azurite
Barbierite (?)
Barytocalcite
Biotite
Borax
Brushite
Calaverite
Celsian (?)
Chondrodite
Claudetite
Clinochlore
Clinohumite
Colemanite
Crocidolite
Crocoite
Cryolite
Cummingonite
Datolite
Diopside
Dufrenoysite
Epidote
Erythrite
Fassaite
Ferberite
Gadolinite
Gaylussite
Glauberite
Glaucophane
Grünerite
Gypsum
Harmotome
Hedenbergite
Heulandite
Hornblende
Huebnerite
Hyalophane (?)
Jadeite
Kainite
Kieserite
Laumontite
Lazulite
Leadhillite
Lepidolite
Lepidomelane
Malachite
Margarite
Melanterite
Meroxene
Mirabilite
Monazite
Muscovite
Orpiment
Orthoclase (?)
Paragonite
Pearceite
Pectolite
Pharmacolite
Phillipsite
Phlogopite
Piedmontite
Polybasite
Realgar
Riebeckite
Sahlite
Schefferite
Spodumene
Stilbite
Titanite
Tremolite
Triplite
Trona
Vivianite
Wagnerite
Wolframite
Wollastonite
Zinnwaldite

MONOCLINIC DOMATIC CLASS (HEMIHEDRAL)

Scolecite

TRICLINIC

Aenigmatite	Fremontite	Montebrasite
Amblygonite	Melaconite	Turquoise

TRICLINIC PINACOIDAL CLASS (HOLOHEDRAL)

Aenigmatite	Babingtonite	Labradorite
Albite	Bustamite	Microcline
Andesine	Bytownite	Oligoclase
Anemousite	Celsian (?)	Orthoclase (?)
Anorthite	Chalcanthite	Rhodonite
Anorthoclase	Fowlerite	
Axinite	Kyanite	

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